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IMIS FIELD TESTED USER INTERFACE LESSONS LEARNED

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Lessons learned are identified as they have resulted from designing user interfaces for the Integrated Maintenance Information System (IMIS). The report is organized according to user interface issues (e.g., Hardware Portable Maintenance Aid Battery Requirement and Software Tab Groups). Each issue is contained within a section of the document. Within each section, a chronology is presented that shows how each issue was addressed in the various IMIS proof-of-concept systems. Seven different systems were developed as part of the IMIS proof-of-concept programs at Armstrong Laboratory Logistics Research Division. Within the various section of the document, many references are cited to support design decisions. Recommendations for future IMIS user interfaces are also included.

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PREFACE

This paper provides user interface lessons learned for various Integrated Maintenance Information System (IMIS) applications developed for the Logistics Research Division. The primary focus of division projects has been for hardware, software, and user interfaces in support of IMIS Portable Maintenance Aids. Work contributing to user interface lessons learned was performed by a combination of organizations supporting several demonstration IMIS systems. Special thanks is extended to Applied Science Associates, Inc., Computer Sciences Corporation, RJO Enterprises, Inc., NCI Information Systems, Inc., General Dynamics Electronics Systems, Lockheed Fort Worth, and Systems Research Laboratories, Inc. Human factors expertise was sponsored by the University of Dayton Research Institute under Contract No. DLA900-88-D-0393.

IMIS FIELD TESTED USER INTERFACE LESSONS LEARNED

INTRODUCTION

The intent of this report is to identify the major strengths and weaknesses that have resulted from designing user interfaces for maintenance-aiding devices and other systems relevant to the Integrated Maintenance Information Systems (IMIS) at Armstrong Laboratory's Logistics Research Division (AL/HRG). In this report, a chronology of user interface design efforts and subsequent design issues are defined in terms of effective and ineffective solutions. The chronology itemizes design decisions made, the justification for those decisions, and recommendations for future efforts. This format allows the recommendations to be applied to other similar development efforts. The chronology is presented in terms of the primary research programs conducted at the laboratory up to and including future full production implementations of IMIS systems.

This report provides an overview of relevant literature and general analyses of study conclusions pertaining to IMIS development efforts. Several previously written documents were extensively used in compiling information for this report (Quill, 1992a, 1992b; Quill, Wynkoop, & Wampler, 1992; Thomas & Clay, 1988). For additional detail concerning information presented on individual studies, refer to the references cited in this document.

GOAL OF AN INTEGRATED MAINTENANCE INFORMATION SYSTEM (IMIS)

The overall goal of an IMIS is to "provide the maintenance technician with the capability to access all of the technical information (interactive electronic technical manuals, interactive diagnostics instructions, work orders, supply availability and ordering, historical data, training material, etc.) required to maintain aircraft via a single, integrated system, regardless of the source of that information" (Johnson, 1993, p. 1). AL/HRG has instituted an iterative design process which comprises three phases. Tasks accomplished within each of these phases have resulted in an iterative improvement cycle for user interface design. Each phase also includes major hardware and software design goals, all of which were intended to prove the "concept" of an integrated computerized maintenance-aiding system.

EVOLUTION OF IMIS

The IMIS development effort has incorporated a multiphased approach (General Dynamics Electronics Division, 1990; Link, Murphy, Carlson, Thomas, Brown, & Joyce, 1990; Quill, Wynkoop & Wampler, 1992; Thomas & Clay, 1988). Phase I (which was conducted from 1982 to 1987) consisted of two intermediate shop field tests (i.e., two design goals). The Computerized Maintenance Aiding Systems (CMAS I and CMAS II) developed for this effort introduced the basic technology required for presenting technical order data on an automated system (see Table 1).

TABLE 1. IMIS Phases

PHASES	DESIGN GOALS
Phase I	CMAS I CMAS II
Phase II	Portable Computer-Maintenance-Aiding System I (PCMAS I) Portable Computer-Maintenance-Aiding System II (PCMAS II) F/A-18 Portable Maintenance Aid (PMA)
Phase III	General Dynamics Electronics Systems (GDES) F-16 IMIS Interactive Electronic Technical Manual (IETM) Presentation System (IPS)

From 1986 to 1992, Phase II expanded the scope of the IMIS effort. During this phase, field tests were conducted in a flight line environment. The Portable Computer Maintenance Aiding Systems (PCMAS I, PCMAS II, and F/A-18 Portable Maintenance Aid [PMA]) developed for this environment required automated diagnostics; extended automated technical data presentation; development of technical data interchange standards; and preliminary examination of the automation of functions, such as ordering parts.

From 1988 to 1994, Phase III provided a full-scale IMIS demonstration system for accessing all information required for a technician to perform maintenance activities at the job site (e.g., Core Automated Maintenance System [CAMS] interface). The General Dynamics Electronics Systems (GDES) IMIS system was developed during this phase. Additionally, the laboratory developed an in-house application, similar to the GDES IMIS system. This Interactive Electronic Technical Manual (IETM) Presentation System (IPS) incorporated many of the lessons learned from a data, software, and user interface perspective (only the user interface lessons learned are included in this document).

USER INTERFACES

Throughout the phases of IMIS development, several design principles have been used to design user interfaces. These principles included flexibility, direct manipulation, error avoidance, and consistency.

Flexibility

Flexibility in design allows all users to readily move from one platform to another, novice users to use step-by-step procedures to accomplish an interface manipulation, and experienced system users to take shortcuts to execute interface actions. Flexibility in design includes being flexible to user needs and being flexible in interfacing to other system components. If technological advances improve the type of hardware available, the user interface should permit easy upgrade to the latest hardware platform. Likewise, if a new method of job-aiding becomes available, the user interface should accommodate this upgrade without revising the entire application.

Direct Manipulation

Direct manipulation is a means of achieving consistency. Consistency refers to "an agreement of logical coherence among things or parts, compatibility or agreement among successive acts, ideas, or events" (Houghton Mifflin Company, 1982). A direct manipulation interface permits the user to point at visual representations of objects and actions, to carry out tasks rapidly, and to observe the results immediately (Shneiderman, 1992). When a method of achieving direct manipulation has been defined and standardized in the design, many aspects of consistency in design are achieved.

Reduction in Errors

Systems that utilize good direct manipulation methods and that implement other consistency design features can, as a result, reduce user errors (Shneiderman, 1992). A simple example can be illustrated through a log-out scenario. When a user quits a session (i.e., logs out), the system automatically prompts the user (through a dialog box) to save the session. Through a few keypresses (mostly confirming the file name to be saved) the user can save the work or discard it. Without this type of direct manipulation prompt, errors of omission could be made (e.g., the user could quit without remembering to save) or errors of commission could be made (e.g., the user could inadvertently save the work under the wrong name).

Consistency in Design

Within the various disciplines associated with the IMIS development process (e.g., user interface design, software design, hardware design, and data development), an overriding design principle has been maintaining consistency. Consistency has played an important role in development efforts, especially in the human-computer interface domain, whether it has pertained to the ability to transfer the technology from one aircraft environment to another or to the ability to take skills and knowledge obtained in other situations and use them in the IMIS environment. Thus, as noted in this report, consistency — although normally thought of as a user-interface issue — has played and will continue to play an important role in all aspects of IMIS development, including data, software, and hardware efforts.

The following items exemplify the importance of consistency in all IMIS development efforts.

- User Interface. To facilitate their efforts, maintenance technicians should face the same types of interface widgets as they move from their personal, home computer to the IMIS PMA and the IMIS workstation (e.g., pressing a space bar checks off a checkbox). Consistency among these platforms assists in minimizing learning (e.g., transferring training already attained at home), performance times, and errors. Without consistency, more training time will be required to become proficient and perform the tasks. Also, more errors will be made while using the system which will result in user frustration during system use. These effects will be heightened for technicians with limited computer skills.

- Hardware. The hardware (e.g., mouse, joystick, light pen) must work interchangeably whether the user is in a maintenance shop, an expediter's truck, or a flight line. If this consistency in design is not provided, personnel may become specialized in the maintenance hardware systems they can use and thus will be less able to transition among various job assignments.

- Software. Consistency in software is closely coupled with the user interface but is a separate characteristic. As the underlying software becomes more consistent, the functions and mechanisms to control data, user interface, diagnostics, and so forth are reduced and standardized. Therefore, efficiencies in design time, development time, and access time (e.g., system response time) are obtained.

- Data. Consistency in the format of data makes information much easier to display, implement, and modify. Furthermore, a consistent format allows user interfaces to take full advantage of the structure of the data to implement links (e.g., hyperlinks) to other pertinent information in the database.

Design Principles — Lesson Learned

Overall, the lessons learned for IMIS user interfaces reveal a tendency to concentrate on the design of hardware user interface issues (e.g., the size of the keys) rather than on the design of software-related issues (e.g., data, screen design, etc.). For example, front-end field tests are rarely performed on sample screens, and state and transition diagrams are generally an afterthought of the design process. Obtaining user feedback through *early* testing of software interface requirements (e.g., using state and transition diagram information) provides concise data and software specifications. Functional requirements of an IMIS system (or any software and hardware development effort) must be driven by user requirements (i.e., requirements obtained and refined through data collection, analysis, and iteration). Thus, the user interface can be designed using actual requirements, available data tagging schemes (Department of Defense, 1992a), hardware capabilities and constraints, and software development tools (e.g., digital graphical user interface builders and off-the-shelf languages). In this way, the user interface unites and manages all system components into one package which is readily usable.

DOCUMENT OVERVIEW

The remainder of this document is organized according to the design goals for each phase. Where applicable, a discussion of each issue begins with the design goal in which it was first implemented and concludes with recommendations for future implementations.

HARDWARE

Case Enclosure

The primary hardware goal of a PMA development has been to design a lightweight, portable, ruggedized computer which can display all necessary information for aircraft maintenance (predominantly targeted for the flight line environment). Phase I activities did not include any hardware development.

Phase II

The goals for the PCMAS I and PCMAS II development efforts were to build the portable device to weigh approximately eight pounds. Ruggedization was only moderately attempted in these two designs because: (1) these devices were proof-of-concept efforts, and (2) subsequent efforts (i.e., GDES PMA) were to address ruggedization requirements. The primary goal was to build lightweight, portable devices for maintenance aiding. The initial PCMAS designs were slightly over the eight-pound weight goal.

However, the PMA built for testing on the F/A-18 aircraft met the weight goals set by the laboratory (under 10 lbs) for portable aids. Additionally, the device was reduced to a bezel-type configuration, under the assumption that a PMA smaller in length, width, and depth would be more widely accepted by users. However, a field test at Edwards Air Force Base (AFB) (Applied Science Associates, Inc., 1990) comparing several hardware design configurations demonstrated that technicians prefer a design larger than the F/A-18 PMA design. PMA design goals important to technicians include:

- the ability to pick up or set down the PMA with one hand;
- "shock absorption" edges on the PMA (allowing users to set down the PMA easily and move it around once it is on the ground);
- the ability to hold the PMA at its center of gravity while using it (this resulted in the extended length of the Phase III PMA); and
- the ability to carry the PMA with other work items, such as a toolbox (this resulted in a strap design).

Given these design goals and the necessity to design a ruggedized PMA, the case enclosure designed by GDES for the F-16 PMA was somewhat different.

Phase III

The GDES F-16 PMA resulted in hardware that increased the height of the PMA to heights similar to that of the PCMAS II (e.g., nearly twice the height of the F/A-18 PMA). The GDES case was the first to meet the ruggedization, weight, and portability requirements for the PMA.

Lessons Learned

An assessment of case enclosure configuration and materials revealed that designs should permit easy swaps among hardware cases. When coupled with perpetual upgrades in computer electronic technology, the case housing all the components is bound to change frequently; designs should accommodate these changes.

Power Switch

Phase II

The power switch on both the PCMAS I and PCMAS II is a conventional two-position toggle switch — when toggled to one position, power is on; in the other position, power is off.

The F/A-18 PMA power switch is a momentary push-button that allows the user to manually turn on the device; however, the software is used to turn off the PMA. Users turn off the PMA by entering the menu system and engaging the quit sequence. (An "Off" switch is not included in order to eliminate inadvertent system shutdowns — that is, accidentally turning off the system). The hardware permits a backdoor, manual reset function which the user initiates by simultaneously pushing the "On" and "Backlight" push-buttons. However, the initial design offered no means to manually turn off the system using the hardware. Later in the design process it became necessary to design a backdoor means of turning off the PMA; therefore, a three-keypad-key combination was used for emergency shut-off conditions.

Phase III

The "On/Off" switch of the GDES F-16 PMA is recessed to minimize inadvertent shutdown; however, the operating system (UNIX) requires a "graceful" shutoff. That is, shutting down the system before executing the appropriate save functions could require the reloading of data or could result in the loss of data gathered during a session.

Final analysis of the "On/Off" switch on the GDES F-16 PMA produced the following assessment:

> Location and design of the power "On/Off" switch is awkward. The switch is located on the right side of the box where users frequently hold the PMA. The switch is a two-position, standard toggle, which is mostly (not entirely) recessed. In a UNIX environment, where inadvertent deactivation of the PMA can corrupt the file system, this design requires modification. The switch should be a locking toggle switch or guarded toggle switch, totally recessed. Ideally, it should be moved to the top of

the box (away from connectors which are frequently accessed) where users do not frequently hold the PMA.

Lessons Learned

Neither the design of the F/A-18 nor the GDES F-16 PMA seemed to address the power switch issue adequately. Some considerations for future developments include:

- under normal circumstances, perform graceful shutoff without losing data (e.g., saving sessions, and database);
- under normal circumstances, perform graceful shutoff without damaging the operating system;
- under normal circumstances, deter the user from intentionally shutting off the power prior to normal shutdown procedures; and
- under abnormal circumstances, permit the user to shutdown the system without having to remember awkward keypresses.

Connectors — Lessons Learned

In Phases II and III, connectors have been consistently placed on the top portion of the PMA cases. These connectors typically have been used for RS-232 connections, 1553 connection; Keyboard port; external alternating current (AC) power; and antennas for radio frequency (RF) modems. These connectors are placed on the GDES PMAs at a distance of 0.75 to 1.0 inch, measured from center to center of the connection. This design requirement allows the connector to be hooked up with bare hands and gloves. No tools are required to remove the connectors on the GDES PMA. Placement of connectors has proven acceptable in field tests conducted at Armstrong Laboratory (AL).

Placement and separation of connectors for future systems should use the 0.75 to 1.0 inch center-to-center arrangement from previous IMIS designs. Additionally, connector hook-up should require no tools so that connections can be made easily.

Limited Keypad

Keypad Key Dynamics

Force and resistance requirements for the PMA keypad keys differ from a standard keyboard in that: (1) the ruggedization requirements imposed on the design limit the types of keys which can be used, (2) the use of arctic gloves imposes slightly different requirements, and (3) the actual keypress action could potentially be more of a push than a press (e.g., if the user is bending over and extending an index finger to display the next screen of information, a "push" force might be exerted rather than a touch or press-type force).

Military Standard 1472-D (MIL-STD-1472D) (Department of Defense, 1989) makes recommendations on resistance and displacement for push buttons (other than those used on keyboards) and keyboards. The PMA keypad is not intended for "touch typing," however, keying is required. The MIL-STD calls for keyboards to be set at a minimum resistance of 0.9 oz and minimum displacement of 0.03 in. Maximums for these settings are a 5.3-oz resistance and a 0.19-in. displacement (Department of Defense, 1989). For single-finger push buttons, the settings in MIL-STD-1472D are 10 oz (min.) and 11 oz (max.) for resistance, and 5/64 in. (min.) and ¼ in. (max.) for displacement.

Key Size

The question of the size of hard keys and the inter-key spacing (between two adjacent keys) was posed several times in the course of IMIS development. The issue pertained not only to the needs of a bare-handed technician but also to the technician who is wearing arctic gloves. Additionally, the findings were to apply to the 95th percentile for Air Force personnel hand size measurements.

The Human Factor's literature offered several suggestions for keytop sizes. The suggestions were:

1. The size of the top of the key should be designed at 0.5 in. for a bare hand (Alden, Daniels, & Kanarick, 1972; Department of Defense, 1989), and a minimum of 0.75 in. for a hand in an arctic mitten (Department of Defense, 1989).
2. Interkey spacing should be 0.75 in. from keytop center to keytop (Alden, Daniels, & Kanarick, 1972) for a 0.5-in. key and 1 in. from keytop center to keytop center for a 0.75-in. key (Department of Defense, 1989, March 14).
3. The following criteria should be considered in key resistance and displacement designs (Boff & Lincoln, 1988); however, in general, force and displacement have minimal effects on keying speed and error rate performance:

   - Reduced key travel (the amount of depression) is preferred for most applications.
   - Increased key resistance is preferred for most applications.

Phase II. The PCMAS I keypad is composed of 25 keys. The keys, white characters on a black background, consist of F1 through F8, 0 through 9, Back Space, Enter, four directional arrow keys, and Select.

The PCMAS II keypad includes 32 keys. In contrast with PCMAS I, the keys are black characters on a white background (see Fig. 1). Similar to PCMAS I, the keys consist of 0 through 9, Erase (ERA), Enter (ENT), Next (NXT), Back (BCK), Return (RTN), More/Less (M/L), Information (INF), Option (OPT), Table of Contents (TOC), Control (CNT), three blank keys, eight directional arrow keys, and Select (SEL).

The F/A-18 PMA keypad design imitates a bezel-type layout (used in most aircraft multifunction displays). The bezel-type layout is based on a menu-driven interface; the menus are accessed by depressing hard keys adjacent to each edge of the screen.

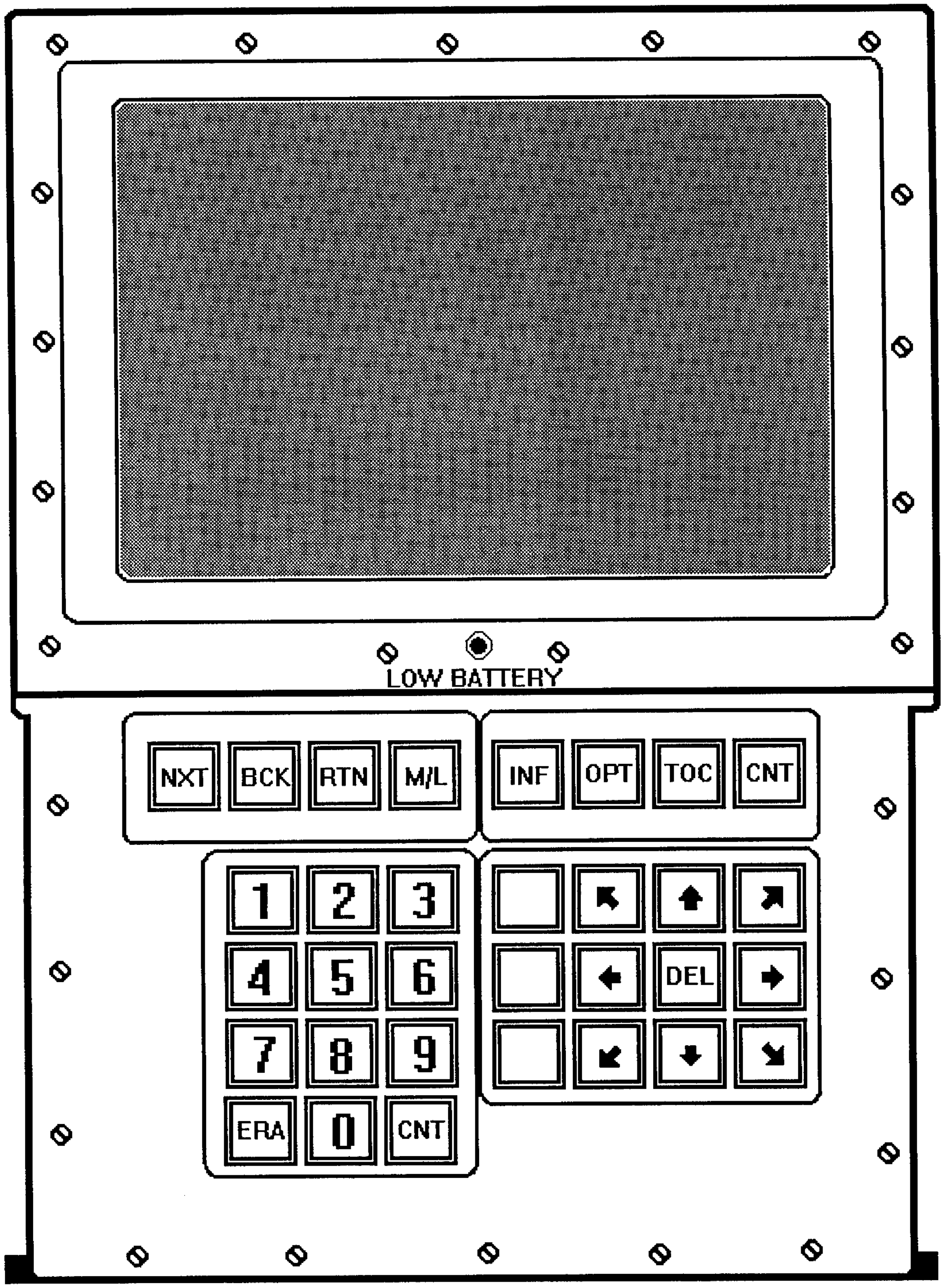


Figure 1
PCMAS II

Although the hard keys allow menus and function buttons to be accessed on all sides of the screen, the interface was designed to provide menus and function buttons adjacent only to the hard keys at the top and bottom of the screen.

The bezel-type design resulted in the configuration shown in Fig. 2. Thirty two keys are dedicated to functions such as cursor movement, numeric entry, programmable soft keys, navigation, and screen manipulation (e.g., menu activation). Additionally, this aid includes a knurled thumb knob for control of cursor movement. Each key was designed and built to be 0.75 in. high and 0.75 in. wide, with 0.25 in. between keys. The only exception was the primary "NEXT" key which was at least two times the height of the other keys (width was the same).

Phase III. Due to flight line maintenance requirements, a membrane-type keypad was specified for the Phase III PMA. Specifications for force and resistance for membrane keypads were difficult obtain. As a compromise between the push button and keyboard specifications outlined by MIL-STD-1472D, a 10-oz resistance and 0.1-in. displacement were recommended for usability testing on the GDES PMAs (see Fig. 3). Heuristic evaluation of the GDES keypad resulted in several global comments including:

- The bubble-dome-type keys used on the PMA do not always activate when pressed. Unlike standard keyboard keys, the keys on the PMA can be depressed but, if "contacts" are not made, a keypress event is not initiated. Contacts are not made unless the key is pressed directly in the center.
- The force required to depress PMA keys is too high. Resistance should be lowered so that keypresses can be made more easily.

Key Color and Lighting

The PMA was designed for use in a variety of conditions, including both day and night situations. To assist in visibility at night, the screen was designed on PCMAS II, the F/A-18 (Phases II), and GDES PMAs (Phase III) with a backlight. In response to a question concerning the visibility of the keypad keys at night, a usability test, conducted at AL/HRG, compared several different keypads. This test determined that in very low-light situations (the only light source was the PMA screen backlight) the PMA keypads as designed at the laboratory were not visible. However, when the PMA screen was tilted at an angle less than 180 degrees with respect to the keypad, the keypad key lettering became visible. In this configuration, black keys with reflective or luminescent lettering were most readable at low-light levels. Consequently, the screen and keypads should be capable of being positioned at an angle between 90° and 180° with respect to each other.

Illumination of the keys on the keypad has been carefully considered in PMA design. However, illuminating the keys would utilize too much DC power. Therefore, setting the keypad and screen at an appropriate angle is a more effective solution.

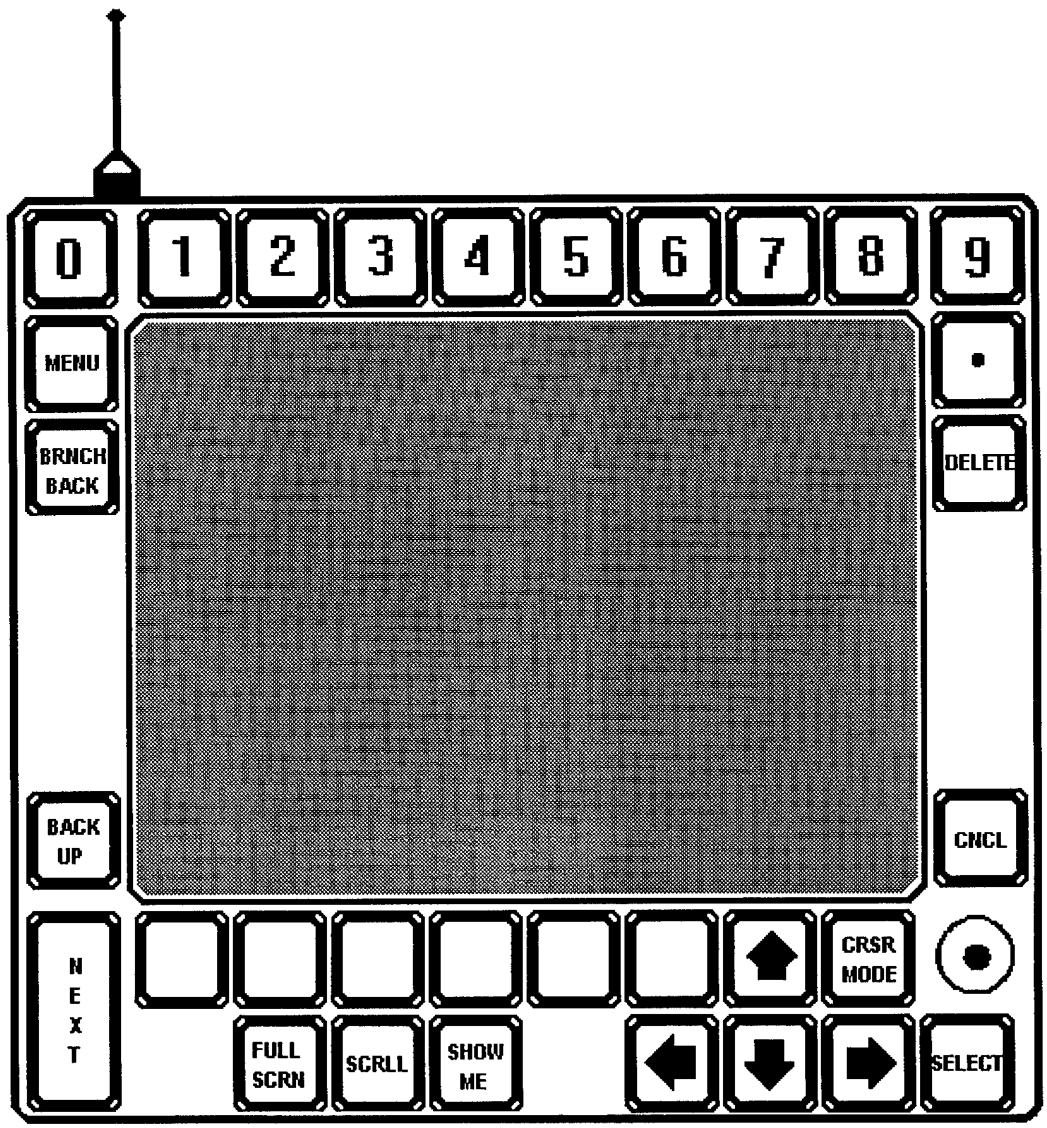


Figure 2
F/A-18 PMA

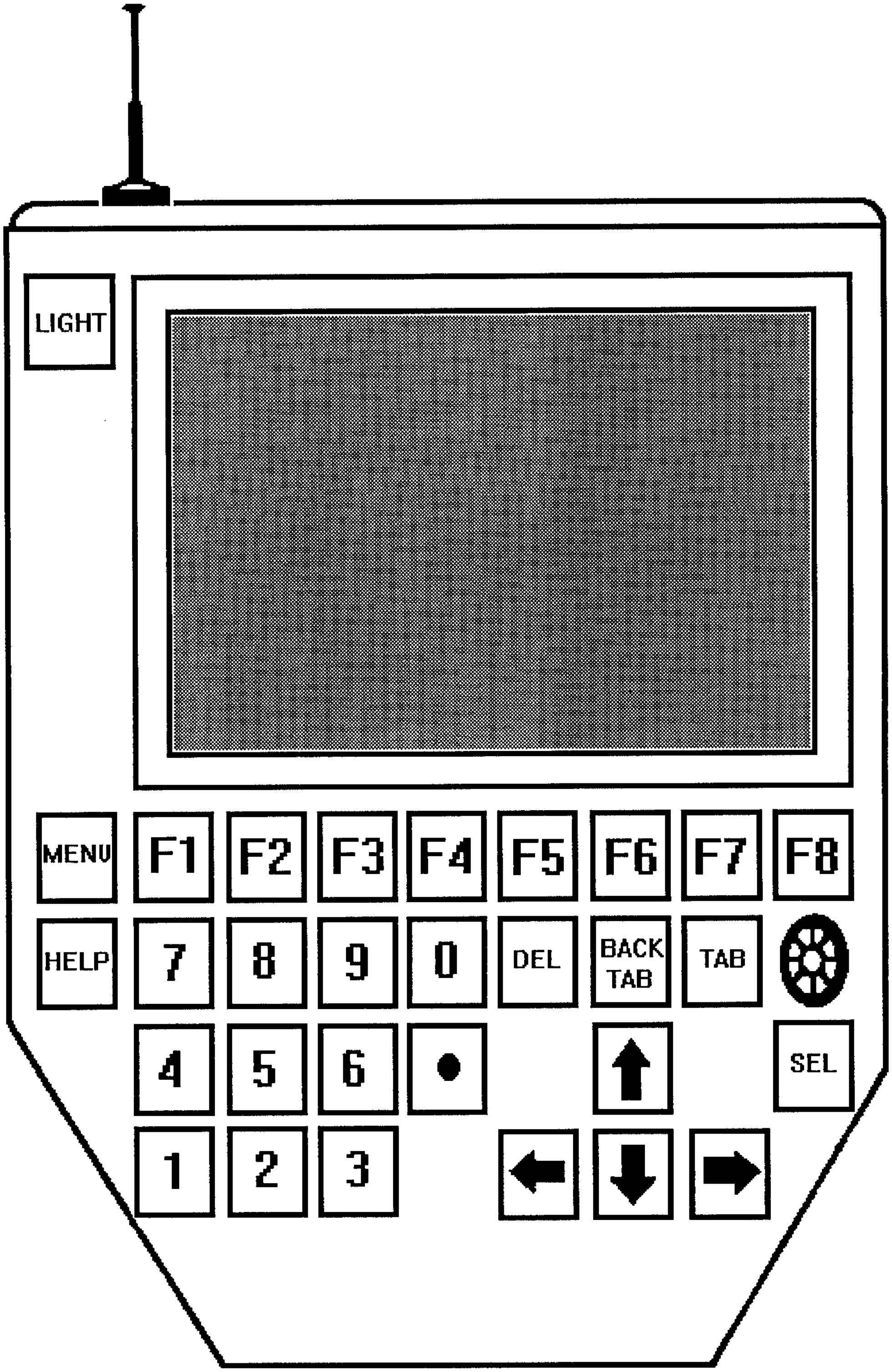


Figure 3
GDES PMA

Lessons Learned

A final analysis of keypad dynamics, key size, key color, and key configuration confirmed that standard QWERTY-arranged keyboards would be the most cost effective for maintenance applications. Each time a new hardware or software component is added to an integrated maintenance system, customized keypads must be re-evaluated for their effectiveness with respect to the new component. Thus, this seemingly minor piece of hardware quickly becomes a bottleneck in system upgrades and modifications (for both software and hardware integration). Therefore, although standard keyboard arrangements (i.e., QWERTY arrangements) must still accommodate the rugged environment posed in flight line maintenance, they are still logistically easier to accommodate. That is, even though standard keyboards may not withstand the environmental stressors imposed on the flight line, they may be significantly easier to replace than customized keypads. When standard keyboards are used, the QWERTY or Sholes arrangement should be used over an alphabetical arrangement (Hirsch, 1970; Kinkead, 1975; Michaels, 1971; Norman & Fisher, 1982).

Cursor and Pointer Controls

During the course of IMIS development, questions have been raised concerning cursor movement and the various methods available to move the cursor.

Phase II

The F/A-18 PMA provides arrow keys and a thumb knob, both of which the technician can use to move the cursor. Both methods produce the same type of cursor movement (e.g., the arrow "up" button and the "up" thumb knob movement move the cursor up one selectable item); however, several factors (in relation to the task of moving the arrow keys versus thumb knob) still require further investigation. To study this situation, criteria for the tasking, and mechanisms to study these criteria were needed. These criteria and mechanisms were provided to two Air Force Institute of Technology (AFIT) students and their Armstrong Laboratory thesis monitor to further IMIS development in the area of cursor movement (Streff & Gundel, 1992).

The criteria for the tasking focuses on two key issues: (1) which input device is better overall, and (2) which input device is better for various applications within the tasks. The task itself is not as important as the applications or uses required for the task; therefore, the mechanisms chosen to study these criteria are two wire repair tasks (Session 1 and Training Session 2 from the F/A-18 test data). These tasks could be designed to be very similar not only in time but in content as well. Within each task, various cursor movement activities could be forced through a script. The cursor movement activities could be made to include the following:

1. Moving the cursor and selecting something within a dialog box.
2. Moving the cursor and selecting an item within a menu.
3. Moving the cursor and selecting radio buttons within text.
4. Moving the cursor and selecting check boxes within text screens.
5. Moving the cursor and selecting graphic diagnostic blocks.

Within each task, these movement activities could be modified or added to (for the particular path within the task) as time permits or as further variations are identified. Identification of the tasks, paths through the tasks, and the list of movements was a start for the AFIT students. The purpose was to assess subjective evaluations and time measures to determine, respectively, which input device is preferred and which results in faster times for each type of application.

The students were given some "rough" scripts of the wire repair sessions which they reviewed carefully to identify the exact path and cursor movement activities to be performed. The method for presenting scripts to subjects (e.g., verbal or written presentation) was also determined by the AFIT students prior to collecting the data.

Lessons Learned

Results of the AFIT study indicate there is not a significant difference in the time required to perform the task using the arrow key versus the thumb knob; however, qualitative data clearly show a preference for the arrow keys over the thumb knob (Streff & Gundel, 1992). Thus, the results of this study are that future designs should rely on arrow keys for cursor and pointer control.

Additional factors must be considered when designing an input device. In particular, the flight line includes environmental factors such as grease, dirt, sand, and the like. Therefore, a track ball must be able to withstand having sand blown over it, in it, and so forth. Given these considerations, a limited number of input device types can be considered. Therefore, until "ruggedization" of input devices occurs, the arrow keys remain the most effective means of moving the cursor and pointer.

Prop

The prop is the device used to hold a PMA upright when it is placed on a flat surface.

Phase II

The PCMAS I prop can assume five different positions (evenly positioned within a 145° angle). In one position, the prop can be used as a handle. This prop, a commercially available lab equipment handle made of steel, attaches to either side of the case. The prop can be released from the case by pushing both sides of the prop toward the case (a push-to-turn handle/prop).

The prop on the PCMAS II can be positioned at eleven angles (evenly positioned within a 300° angle). Like PCMAS I, it allows the user to carry the PCMAS II when using the prop as a handle. The prop is a commercially available lab equipment handle, made of plastic, which attaches to either side of the PMA case. The prop can be released from the case by simultaneously pushing two buttons located on the prop/handle sides (a push-button-to-turn handle/prop).

The appropriate height of the F/A-18 PMA, where a prop is used, was determined by using several parameters. The goal was to determine the height that provides maximum visibility for the 5^{th} to 95^{th} percentile body measurements for United States Air Force (USAF) personnel, looking at the PMA on the ground or on a table, while standing at a distance of three to five feet. A secondary concern was the ability to position the PMA on a table such that people standing around the table would be able to view the screen contents (e.g., for demonstration purposes). Specific information for each of these criteria were gathered (USAF personnel height [Van Cott & Kinkade, 1972], PMA Ovonics screen visual angles, etc.) and calculations were made to determine the prop angle degrees required for optimal viewing of the PMA.

The optimum angle between the PMA and the ground was calculated to be 24°. This angle assumes viewers will be standing and observing the PMA at the propped angle either on the ground or on a table. When using this dimension to design props in the future, designers should carefully determine the actual prop height using the dimensions of the individual PMA to accommodate this angle.

Lessons Learned

A prop should be designed which allows the PMA screen to be at a 24° angle with respect to the ground/table. Additional prop angles can be added to accommodate various PMA screen positions.

Straps and Handles

Phase II

PCMAS I and PCMAS II do not have a strap for carrying purposes. The prop, when in the parallel position, is designed to be used as a hard, fixed handle (thereby eliminating the need for a carrying strap).

The F/A-18 PMA does not have a hard, fixed handle. Instead, it has a strap which could accommodate use as a carrying handle or a long, over-the-shoulder strap. The strap on the PMA is designed (e.g., length, width, clasps, etc.) using information found during a field test conducted at Edwards AFB, CA (Applied Science Associates, Inc., 1990), MIL-S-40022E (Department of Defense, 1985), and other design reference sources (Van Cott & Kinkade, 1972). Strap designs should include the following features:

1. Length of the strap should be approximately 3'8". This will accommodate the 95^{th} percentile body measurements for the USAF man or woman. Personnel at Edwards indicated that the long strap "allows you to put it over your neck and shoulder and slide it around back to prevent swinging." (For example, when carrying the PMA to the flight line, it could be positioned on the back to prevent it from swinging while walking). The length used at Edwards varied from 17" to 3'7"; technicians preferred the longer strap (they also wanted the ability to adjust the strap to a shorter length).
2. The width of the strap should be approximately 2". The width of the strap used at Edwards was 15/16" and personnel indicated that they would have preferred it to

be "...up to 1" wider...." The two-inch-wide strap will accommodate 2.5th percentile body measurements for the USAF woman.

3. The necessity for a shoulder pad on the strap was not found in any of the data searches made.

The final design of the F/A-18 strap allows for the strap to be folded into a bi-fold (three layers) position which accommodates a handle-type configuration. When unfolded, the strap also accommodates the long, over-the-shoulder, configuration.

Lessons Learned

The key to design of handles or straps is to (1) permit the user to readily pick up the device (e.g., using a handle), and (2) permit the user to carry the device without using any hands (e.g., using an over-the-shoulder strap). The design for the F/A-18 PMA served both of these functions effectively.

Battery/Power Requirements

Phase II

PCMAS I and PCMAS II batteries were silver zinc batteries — one battery pack per PCMAS (approximately 22 battery cells per pack). The batteries are rated at 5 amp hours (i.e., drained at 5 amps, it will last for 1 hour). Operating voltage for a battery pack is between 22 and 32 volts. The system operates at approximately 27 watts; therefore, each battery pack provides the system at least five hours of operation.

The batteries were external battery packs attached to the PCMAS I and II through a cable.

The F/A-18 PMA uses the same type of silver zinc batteries; however each battery pack consists of only 11 battery cells per pack. The amp hour rating is the same (5 amp hours). The operating voltage for each battery pack is 11 to 16 volts. The system operates at approximately 17.55 watts, thereby, allowing the system to operate at least 3.8 hours per battery pack.

Batteries on the F/A-18 PMA are contained in a battery case which is mounted to the PMA case as an integral unit. On one end, the battery case is attached by a connector; on the other end, it is connected by a dovetail slide mount. This arrangement allows the battery case to be attached and detached from the PMA case without the use of additional tools (e.g., screwdriver).

Phase III

The GDES F-16 batteries use nickel cadmium batteries. These batteries were chosen in an attempt to reduce cost. (Silver zinc batteries are $75.00 per cell; nickel cadmium batteries are less than $7.00 per cell.) Each battery pack on the GDES F-16 PMA consists of six battery cells per pack. The batteries are rated at 5 amp hours. Operating voltage for the battery pack is between 6.7 and 9.4 volts. The system operates at approximately 9 watts; therefore, each battery pack provides the system at least two hours of operation.

Six batteries, encased in shrink-wrap, form a pack. This pack is placed in the battery compartment of the PMA (as opposed to a totally detachable compartment or case as used on the F/A-18 PMA). The battery compartment can be accessed by loosening eight Southco quick-release fasteners. The fasteners are loosened with a quarter turn of the screws that hold them in place.

Lessons Learned

The requirements for the portable battery/power can be reduced to the following list:

- Assure the batteries can be readily obtained (i.e., no special design or configuration is required). For example, camcorder batteries would be good.
- Assure the batteries are lightweight.
- Assure the batteries provide several hours of uninterrupted power.
- Assure the battery charger provides for discharging of batteries if that is a desirable feature of the battery.
- Assure batteries are quickly and easily removed without the use of any tools.

One final note concerning battery configuration: the system, as a whole, should allow for a "Hot Swap" of batteries. That is, while the system is on, (1) the system must be able to notify that battery power is low, (2) the user must have adequate time to replace the batteries, and (3) the battery swap should be possible without turning off the system and without losing any data.

Screens

Touch Screen as an Option

Examination of input devices has commonly led to the question, "What type of input device would best serve technicians' needs with a PMA?" The following information is provided as an initial assessment of the potential application of a touch screen to the IMIS environment.

A touch screen input device responds to inputs created when the user's finger touches a particular area of the display screen. The user navigates through the system by pointing at particular areas of the screen to make selections. A typical display includes menu items enclosed in boxes which resemble buttons. The user "presses" the buttons that will lead to the desired information. Because of this direct navigation capability, touch screens are quite useful in menu selection tasks.

The primary advantage of a touch screen device is the direct relationship between the user's input and the displayed output. There is direct hand-eye coordination because the input device is also the output device. The result of this direct relationship is a system that provides faster response times and is easier to learn than some other interaction devices (e.g., Karat, McDonald, & Anderson, 1986). Conversely, indirect pointing devices (e.g., a mouse, thumb knob, or graphic tablet) do not have a direct relationship because they are removed from the display (Greenstein & Arnaut, 1987; 1988). The PMA cannot support all input devices that are removed from the display (e.g., mouse or graphic tablet) because of its size constraints; however, it does support arrow keys (hard keys) and the thumb knob (joystick-type device).

Another advantage of the touch screen is that users do not need to memorize commands (e.g., cursor movement schemes, etc.) because all valid inputs are displayed on the screen. Thus, the interface is easier for novices to use and reduces the amount of training required.

The primary interface for the PMA is menu-based but also requires the selection of small items in graphic displays. A touch screen would be very beneficial for the menu selection type tasks (assuming the targets or selectable regions are large enough) but would not be adequate for fine detailed pointing such as that required for graphic component selection. This problem could be resolved by using a stylus for pointing instead of a finger. A stylus may be used with some touch screens as an alternative to touching the screen with the finger. However, a stylus requires a pointing gesture that is less natural, and the user must either continuously hold the stylus or pick it up before each use. Furthermore, maintenance technicians would need to use their hands to make repairs while operating the PMA; therefore, they would not be able to hold the stylus at all times. Consequently, the stylus would need to be attached securely to the PMA to reduce the chances of it creating any foreign object damage (FOD).

Of course, there are disadvantages associated with the use of touch screens. One is that users must be within an arm's reach of the display. This will not be a problem with the PMA because, with the exception of voice activation, alternative input devices also require the technician to be an arm's length away. However, fatigue may occur from the continual lifting of the hand/arm to the display. Additionally, during use, the finger, hand, or arm of the user may block the view of the screen. This problem is inherent to the direct relationship devices (e.g., touch screens, light pens, and styluses) (Greenstein & Arnaut, 1987; 1988).

Another disadvantage is that some overlays that cover the touch screen may become scratched easily. Thus, durability is important in PMA design considerations. Furthermore, a literature review by Gould et al. (1990) provided evidence of an increase in user errors when a touch screen is used (e.g., users inadvertently activate the wrong area).

The main disadvantage of using a touch screen for the PMA is the work environment. The PMA was designed for maintenance technicians to use while repairing aircraft. The environment in which these technicians work is not very clean. For example, the technician is likely to come in contact with dirt, grease, and various fluids which will interfere with the use of a touch screen. Most touch screens are enclosed; thus the concern is not with damaging the device, but with decreasing its functionality. If the technician touches the screen with dirty hands, the substance will obscure the screen, making the display more difficult to read. Additionally, the system might be inadvertently activated by dirt on the screen (Greenstein & Arnaut, 1987; 1988).

A stylus could be used to avoid touching the screen with dirty hands, but the screen would still respond to the user's finger. Therefore, there is a great likelihood that the technician will be tempted to use a dirty finger instead of the stylus. Also, there is a concern about the stylus creating FOD in the aircraft. To avoid this potential problem, the stylus could be attached to the PMA by a cord; however, this would reduce usability further.

With the exception of environmental factors, a touch screen is suitable for use with the PMA. However, problems with dirt and grease have such a high likelihood of occurring that the touch screen is an impractical device. Therefore, the PMA should NOT use a touch screen as its input device.

Phases II and III

Information about various characteristics of liquid crystal displays (LCDs) was required for screen purchasing criteria and design review criteria. Three screen types were reviewed in relation to specified contrast ratio, viewing angles, resolution, and wattage. These screens are: the Ovonics screens (purchased for the PCMAS II and used on the F/A-18 PMAs and PMA(x)s), Epson screens (to be used for the PMA and PMA(x)) (Epson America, Inc., 1991) the Kyocera screens (to be used for the IMIS PMA) (Kyocera, 1991).

The screen data suggest that PMA use may be limited with viewing angles of only 50° (i.e., 25° from the midpoint to either side of the box). In other words, a user could not stand at an angle of more than 25° from the midpoint of the screen and be able to view the screen text. However, usability tests would be needed to provide data to support or reject these conclusions. Notably, oblique viewing angles of 32° off center are at the outer limits of legibility (Morrissey & Chu, 1988).

Usability tests (and performance tests) demonstrated that the Ovonics screens provide excellent display qualities; however, their cost is prohibitive. The Epson and Kyocera screens, on the other hand, are reasonably priced. Furthermore, as shown in Table 2, the Epson screens and the Kyocera screens have similar contrast ratios, viewing angles, and resolutions; however, the adequacy of these features is in question. Because features of the two types of screens are so similar, it was suggested that a human factors group conduct usability tests to determine whether either or both screens would meet the needs of the IMIS field test.

A primary problem with LCD screens is glare. However, the problem is especially noticeable when the screen is used in direct sunlight. One solution to this problem is glare filters, which reduce the glare associated with the current screens. These optical glare filters often have Velcro fasteners which allow them to be easily attached or removed from the screen. The filter should be selected carefully to ensure the appropriate one is used. If the proper filter is used, black characters will actually appear blacker on the display than they do without the filter (this could also improve the contrast ratio problem identified below). Greenstein & Arnaut (1987) state that if touch screens are used, layering effects and viewing angle parallax problems with filters should be considered.

TABLE 2. Screen Specifications

Manufacturer	Feature	Specification
Ovonics		
	Contrast Ratio:	20:1
	Viewing Angle:	110 degrees side to side 135 degrees top to bottom
	Resolution:	80 dots per inch
	Watts:	3.5 2.5 more for backlight
Epson		
	Contrast Ratio:	9:1
	Viewing Angle:	40 degrees side to side 50 degrees top to bottom
	Resolution:	80 dots per inch
	Watts:	0.4 2 to 3 more for backlight
Kyocera		
	Contrast Ratio:	8:1
	Viewing Angle:	50 degrees side to side 50 degrees top to bottom
	Resolution:	80 dots per inch
	Watts:	0.6 3.1 more for backlight

Another design consideration that reduces problems associated with viewing angle and contrast ratio is modification of the font used for presentation. Two modifications could substantially assist in the ability to view the display. The first step is to make all text bold, shadowed, or double-pixel-width. In their study, Uphaus, Barthelemy, and Reising (1990) found that double-pixel-width characters substantially reduce reading errors when displays are degraded (e.g., columns or rows in the dot matrix are missing). These findings could have applicability to other types of display degradation such as contrast ratio. The second step is to enlarge the size of the font. This larger font size should be in accordance with latest minimum font sizes specified in *Military Specification - Manuals, Interactive Electronic Technical: General Content, Style, Format, and User-Interaction Requirements* (MIL_M_87268) (Department of Defense, 1992b). (Viewing distances of three to five feet require a minimum font size of 0.17 to 0.34 inches.)

Subsequent evaluations of the Kyocera and Epson screens showed that, when used in direct sunlight, the screens begin to black out after 15 minutes. Some manipulations produced an additional ten minutes of use before the screens become completely unusable. Thus, all PMA screens should be tested in hot, direct sunlight for the complete duration of their expected use. This type of testing will assist in ensuring that the screens meet the durability requirements of the maintenance flight line.

Lessons Learned

Tests conducted in ambient sunlight indicate that all PMA screens should be tested in hot, direct sunlight for the complete duration of their expected use. These tests also showed that monochrome screen presentations are much more legible than color screen presentations. Therefore, until color screen contrast improves, monochrome presentations are recommended.

As for other specifications, screens that can accommodate the specifications of the Ovonics screen are preferred (see Table 2). These screens, although extremely expensive, adequately meet all screen requirements for adequate viewing in a flight line maintenance environment.

DISPLAY SCREEN REGIONS AND RELATED FUNCTIONS — LESSONS LEARNED

The remainder of this document will not separate designs and lessons learned into specific phases of work. For clarity and flow, it will provide lessons learned with examples from the various phases of work performed.

Cursor Movement and Selection

Tab Groups

Early versions of the IMIS user interface (i.e., F/A-18 PMA and earlier) did not require an abundance of cursor movement among objects on the screen. However, as user interfaces have evolved, it has become necessary to allow the user to toggle among groups of objects on the screen. This capability is characteristically served by grouping on-screen information into chunks of related topics. The user then navigates among these screen regions with the tab key and subsequently uses the arrow keys to select or interact with items in a given region. The GDES IMIS and subsequent IPS development efforts have incorporated this feature into the design. As a general rule, when defining tab groups, similar functions should be grouped, then sequential cycling through the groups should then be permitted by pressing the tab key specification (Wampler et al., 1993).

Pointer versus Cursor versus Focus versus Default

To assure appropriate functionality, clear distinctions must be made among pointer, cursor, active focus, and default screen items. The *pointer* is the object on the screen that moves when the mouse, joystick, or trackball is "rolled" (i.e., no clicks are associated with this movement). The pointer is generally represented by one of a variety of shapes, such as an arrow or an I-beam. The *cursor* is the object that indicates the location of keyboard focus in an active region. The cursor can be shown in a variety of shapes, such as a vertical bar or a highlighted menu item. Several areas on the screen can have a cursor; however, only one cursor location can have active focus. *Active focus* refers to the screen region in which user commands (i.e., typing on keyboard, clicking mouse button) will register. For example, if the menu bar has active focus, subsequent keystrokes will execute the associated commands corresponding to the menu bar. Certain cues are provided to indicate active focus, such as blinking or highlighting. A default screen item is the one push button, in a series of push buttons, that has an emphasized border. If the push button has a default border, pressing the Enter or Return key will activate that push button.

For example, in most Microsoft Windows applications, the user can position the pointer on a dialog box push button and click the mouse to activate the item. Alternatively, the user can press the tab key to move the cursor around the dialog box. This action would eventually move the active focus onto the defaulted push button. Once the active focus is on the desired push button, the user can then press Enter or Return to activate this button.

Differentiation of these functions is critical in designing user interfaces. Duplicating the accessibility of items permits users to choose a method most appropriate for their application and does not limit the hardware implementations used for the maintenance aid.

The F/A-18 presentation system does not provide pointer functionality, and cursor functionality is limited in that it is always tied to the active focus. Defaults are provided, however, they are permanently fixed (e.g., always on one push button). This limitation in functionality forces users to interact solely with the keyboard when running the software (i.e., mouse or joystick functionality is not available).

The GDES presentation system, as built for the IMIS Field Test at Luke AFB, incorporated a cursor, a pointer, active focus, and defaults; however, the UNIX environment, rather the User Interface Builder in UNIX, did not permit appropriate implementation of these functions. These implementation problems were especially confounded by the limited number of keypad keys and the limited thumb knob capabilities. Some resulting problems were difficult to anticipate but very obvious once implemented. For example, if a dialog box appeared in a location not directly under the pointer, the user had to move the Pointer over the dialog box (with the thumb knob) to accept keypad key events. However, it would have been much more efficient for active focus to have been forced into the dialog box, irrespective of the pointer location. Additionally, the user should not be required to move from one input device (thumb knob) to the other (keypad). Redundancy of functionality should have been permitted so that both input devices worked nearly everywhere. However, designing this functionality into the software as an afterthought became a labor-intensive design requirement, and many corrections were not possible. The key to success in this intricate design area is choosing an interface building tool which provides this functionality and a designer/developer who pays close attention to these implementation requirements up front and throughout the development.

The IPS used a Microsoft Windows environment for development. The user interface tool (Visual Basic, Professional) allowed for pointer, cursor, active focus and defaults. Most of these functions were built in the Visual Basic application (i.e., minimal development was required). In addition, a full-time designer/developer was devoted to addressing the details of the user interface, including fine-tuning these functions to work with a limited keypad and mouse. The built-in functionality provided by this system significantly reduces the amount of time required to make the user interface compatible with other IMIS platforms, such as an eye-piece, or desktop computer.

When a screen of information appears in the IMIS environment, active focus should be initially positioned in the upper leftmost tab group (and the upper leftmost item in the tab group). The caveat for this positioning is that the tab group must contain an item that can receive focus (i.e., non-editable fields would not be permitted to receive the cursor). If the upper leftmost tab group contained a non-editable field, focus would be placed in the next tab group (i.e., cycling through tab groups is done left to right, then top to bottom). This method of focus placement has been incorporated in all applications since the F/A-18 application, and has worked well in all circumstances.

Cursor Movement via Number Selection

Moving the cursor via number selection simply entails using number keys as menu accelerators (e.g., Alt F to access the File menu). The earliest IMIS system to incorporate selection by number was the PCMAS II. In this method, menus could contain any number of items. However, to accommodate the number selection feature, a method was required to indicate when the user was finished typing the number (e.g., when the user pressed "1" was the entry complete, or was the user going to enter another number to make the number "12?"). A separator key (".") was used to indicate the user was finished typing the number. After design and test of this method, it was determined that a simpler method of selection by the numbers was required.

In their study, Carney & Quinto (1993) found that users prefer the quick access capabilities of the number keys to soft key activation or cursor movement activation of menu bar items. In their system, menus are limited to nine or fewer items, and the user chooses an item by simply pressing a corresponding number. In the Carney and Quinto method, after the menu bar has been activated by pressing a "menu" key, the number keys became "hot." As the user presses a number, the corresponding menu item is highlighted and activated (e.g., the corresponding pull-down menu is displayed). This method of selection by number has been designed and implemented in IMIS applications subsequent to the PCMAS II application. Again, the limited keypad restricts accelerator keys to number keys. Additionally, all menus are limited to no more than nine items. Lists longer than nine items appear in a list box instead of a menu.

Autorepeat versus Key Flushing

In some cases, when the user moves between screens, the new display takes longer to draw than the user takes to press the next key. In the PCMAS II application, the "Next" key, used to move between screens, is flushed each time it is pressed (e.g., only one entry is permitted, then all subsequent key presses are ignored until the system is finished "drawing").

In the GDES IMIS application, the same philosophy is used to flush keystrokes when moving between screens. This method is especially useful when movement between screens is slow.

In the IPS environment, interscreen movement times are relatively fast; therefore, autorepeat is permitted for movement between screens. This permits the user to move more readily through familiar screens. The problem associated with this implementation is that the user can "page" through warnings, cautions, notes, and defaulted prompts without having adequate time to see the information being presented (i.e., the system would present them faster than the person could perceive them).

There is a method of accommodating autorepeat without permitting the user to miss "vital" information. If autorepeat is permitted for movement between screens, a different key could be assigned for acceptance of screens with "vital" information (e.g., warnings, cautions, notes, and prompts). For example, the return key would normally move between screens; however, movement between "vital" screens would require pressing some other key.

Keypad Functions

The functionality of backing up has been addressed numerous times in the laboratory in an attempt to resolve the functionality associated with this key. The result is, essentially, a continuous "Undo." However, if the user has branched off to another functional area (e.g., calls up a dialog box to change a setting) and finishes that function (e.g., accepts the dialog box), the backup function cannot be invoked to re-enter the completed function (e.g., the dialog box). This seems logical but can be tricky when backup is used to present technical order procedures.

The F/A-18 presentation system implemented backup in the above manner and was well accepted. In this system, pressing the Backup function presents users with a message informing them that backing up the system will "undo" that step. Subsequent sequential backup keypresses can then be made without repeating the message. Backup is only permitted within maintenance procedures. Once a procedure is complete, the user cannot backup into that procedure.

The GDES IMIS presentation system implemented backup in a similar manner; however, the message is not directed toward the user. Rather, the backup message identifies software and data that will change (these messages were not understood by the user).

Future methods of backing up should use the "Undo" functionality. Using the term Undo rather than Backup would help clarify the true functionality, thereby reducing the need for a message to the user.

A branch back function has been envisioned for IMIS but has never been implemented at the laboratory level. The intent is that if users branch off to another series of information (e.g., branch from procedural information to theory of operations), there should be a hot-key available which allows them to branch back to the first piece of information (e.g., the procedural information). This functionality would not necessarily require new keys, but users should be able to easily move between several screens of secondary information or branch back to their primary work at any time.

On-Screen Keyboard

An on-screen keyboard allows a user to input alphabetical information onto a display screen via an indirect pointing device with a select function (e.g., a mouse incorporating a point and click action, or arrow keys with a select key incorporating a move and select action). Using an on-screen keyboard (i.e., pointing and selecting various regions on the screen, labeled with alphabetical characters) results in the display of the corresponding alphabetical character.

Armstrong Laboratory implemented QWERTY-arranged on-screen keyboards for the F/A-18 and the GDES IMIS applications. However, there were many discussions as to whether a QWERTY or alphabetical arrangement would be better for the on-screen keyboard. Therefore, a separate study (Quill, 1994; Quill & Biers, 1993) looked specifically at on-screen keyboard arrangements. Overall, the results of this study indicate that the on-screen QWERTY arrangement was better for both experienced and non-experienced typists.

A standard QWERTY-style arrangement is recommended for on-screen keyboard arrangements, regardless of whether the input device is a keyboard or a mouse.

Labels, Titles, Captions, Headers, Text, and Characters

Labels, Titles, Captions, Headers

Alignment and capitalization requirements for labels, titles, and headers have been clarified and specified in two documents for the IMIS applications at AL/HRG. For the F/A-18 presentation system, the Common User Interface Specification (Moorman & Quill, 1991) was used. For the GDES IMIS presentation system, the Human-Computer Interface Specification provided additional information on this topic (Wampler et al., 1993).

Both specifications answer questions concerning labels, titles, captions, headers, and so forth, primarily using guidance provided by Galitz (1985). Galitz identifies key issues to consider when designing these fields. The most important issue is to make "identifiers" distinguishable from the rest of the text. This may be accomplished in several ways: (1) make identifiers the opposite case of the text in the field or cell (capitalization or non-capitalization must be rigidly enforced for identifiers and entries), (2) position the identifier differently than the entry (e.g., indent the entry or center the identifier above the column of table cells), or (3) use a unique symbol to distinguish between the identifier and the entry (e.g., horizontal and vertical lines, thicker than the standard line width).

Galitz also notes that three spaces should be left between cell entries in a table. Column headers should be centered above the cell entry, and captions and data fields should be formed into columns. For example:

NAME: ____________________________________
STREET: ____________________________________
CITY: __________________
STATE: __
ZIP: _________
COUNTRY: _________

To differentiate between identifiers and cell entries, Galitz recommends that one or the other should be capitalized. In other words, if identifiers such as "Name" and Street" are not capitalized, the letters filled in by the user should be automatically capitalized. Although it may be easier to differentiate the identifiers in some way other than capitalization (e.g., indentation or unique symbol such as a line), most of Galitz examples of identifiers are in capital letters.

Finally, Galitz notes that rows of information should be divided by some kind of separator placed approximately every five lines (e.g., a horizontal line or an extra space). This display technique assists in guiding the viewers' eyes across the row without losing their place.

Characters and Background

A complex issue in each IMIS development effort is background color, the color of the text on the background, and various methods of emphasizing text (reverse video, bolding, etc.). To emphasize the current step being performed, original screen designs bolded the text on the step. In each development effort, a hardware review (especially when viewed outdoors) revealed that all text needed to be bold to increase readability. Designs were then modified so that reverse video could be used to identify the current step. During the GDES IMIS effort, an extensive investigation was performed on background color (light versus dark), text color (light versus dark), and switching between the two alternatives (light text on a dark background and dark text on a light background). The first issue dealt with whether one alternative improved reading performance more than the other (e.g., was reading improved by having light text on dark background or vice versa). The second issue dealt with special considerations in using reverse video and switching between the two alternatives.

The findings of the investigation revealed that, for readability of characters with respect to background (i.e., light characters on a dark background versus dark characters on a light background), there is no statistical evidence to support one alternative over the other (Oborne & Holton, 1988; and Cushman, 1986). For example, Oborne and Holton (1988) found no significant differences in performance when comparing light text and dark background with dark text and a light background on screen. However, they did find significant differences in subject preferences. (Notably the sample size used in the study was small). Subjects preferred the dark text on a light background to light text on a dark background.

Special considerations for reverse video and switching between light text on a dark background and dark text on a light background are discussed in Galitz (1985). These considerations are as follows:

- There can be potential problems when displaying dark text on a light background if there is excessive brightness caused by the emitted light from the electron gun. (This should not be of concern when using an LCD.)
- Light from a display tends to bleed into the surrounding area; therefore, if the background is light and the text is dark, the background will bleed into the text. On the other hand, if the text is light and the background is dark, the text will bleed into the background. McCormick and Sanders (1982) termed this irradiation. Galitz warns that if character size and resolution are inadequate, the dark characters on the light background may not be as legible as the alternative configuration (i.e., light characters on a dark background). (This may be justification for having text presented as light on a dark background.)
- Flicker also becomes a concern when dark characters are presented on a light background. Refresh rates should be increased to between 90 and 100 cycles per second to eliminate the occurrence of perceived flicker on the screen. For light characters on a dark background, the refresh rates are adequate at 60 cycles per second. (Again, this may be additional justification for having text presented as light on a dark background. Although this is probably less apparent on LCD screens than cathode ray tube (CRT) screens, the effect may still be present.)
- When presenting some information as dark text on a light background with other information as light text on a dark background, allow sufficient margins around the fields to eliminate any legibility degradations. (In the IMIS design, sufficient step separations should alleviate this potential problem.)
- Avoid making displays appear to have a crossword puzzle effect (i.e., switching between the two alternatives too often). Careful alignment and columnization rules should be followed to minimize this effect.

There appears to be no empirical evidence to support the notion that one display arrangement results in better performance than the other; however, there may be some considerations for IMIS in perceived clarity of characters, flicker effects, and border differentiation. The result of these considerations is that text that is to be read, should be presented as light on a dark background. Other text could be presented in reverse video (i.e., dark text on a light background). Additionally, extra design considerations need to be followed when switching between the two display alternatives.

Character Size

For the F/A-18 effort, character size in screen designs was determined based on a user standing between three and six feet from the screen. As the user moves further from the screen, the size requirement for the text is greater. However, due to the limited screen size of the hardware, tradeoffs were required between: (1) what could be read at a distance, and (2) what would fit on the screen. In the GDES application, this same philosophy was used. In both applications, the tradeoffs made did not adequately address readability or screen-space availability. Therefore, in the IPS, adjustments were made for character size depending on the function being performed. That is, if the text is to be read at a distance (e.g., procedures), it must be larger. If an arm's length is required to interact with the information (e.g., selection from a list), character size can be standard CRT character sizes. This compromise has worked well in the application.

According to the General Content, Style, Format, and User Interface (GCSFUI) and American National Standard Institute/Human Factors Society (ANSI/HFS) 100-1988 publication (Department of Defense, 1992b; Human Factors Society, Inc., 1988), a minimum of 16 minutes of arc and a maximum of 24 minutes of arc, with optimal being 20 to 22 minutes of arc, are preferred for reading tasks. Salvendy (1987) cites similar arc minutes. The formula for specification of the character height is in GCSFUI (Department of Defense, 1992b).

The formula provided in GCSFUI for character height specification can only by used for small angles. Under these conditions, height (h) is equal to the angle in radians (θ) times the distance (d) (i.e., $h = \theta \times d$). In the character height formula, the minutes of arc must be converted to radians. To make this conversion, minutes of arc must first be converted to degrees of arc (dividing by 60), then degrees of arc must be converted to radians (dividing by 57.3). Therefore, the character height formula is: character h = (minutes of arc x distance) / (57.3 x 60). The actual character heights for a three-foot viewing distance should be as follows:

$$h = (16 \text{ min of arc} \times 36 \text{ inches}) / (57.3 \times 60) \quad \text{or} \quad h = 0.17 \text{ inches}$$

$$h = (20 \text{ min of arc} \times 36 \text{ inches}) / (57.3 \times 60) \quad \text{or} \quad h = 0.21 \text{ inches}$$

$$h = (22 \text{ min of arc} \times 36 \text{ inches}) / (57.3 \times 60) \quad \text{or} \quad h = 0.23 \text{ inches}$$

$$h = (24 \text{ min of arc} \times 36 \text{ inches}) / (57.3 \times 60) \quad \text{or} \quad h = 0.25 \text{ inches}$$

For a screen which is, for instance, 640 pixels x 480 pixels, these would equate to 13.6 pixels as a minimum character height, 16.8 to 18.4 for optimum, and 20 for maximum. The specific font chosen would have to use these pixel height requirements for a three-foot viewing distance.

Screen Layout and Density of Information

Use of white space (space not used by characters, objects, or other screen symbols) is important to ensure the display screen is not cluttered and to assist in emphasizing important points on the screen. The question of screen density specifications was raised with respect to the design of IMIS screens. The following data were compiled and used in all applications since the F/A-18 presentation system.

The question of screen density becomes more important as character font sizes increase and graphics and other screen displays become more complex. To ensure "good" screen layout, density should not exceed between 15 and 25 percent. That is, a screen of text should not exceed 75 to 80 words; the remainder of the screen should be white space. As graphics, icons, titles, labels, and so fourth are added to a screen, the number of words decreases.

This density specification is stated in the Deficiencies and Recommendation Summary for the F/A-18 Portable Maintenance Aid (Quill, 1992a). Use of white space was not calculated for the F/A-18 presentation system; however, screen density was estimated for the F/A-18 and subsequent applications.

Selectable Items

Selectable items include a variety of "widgets" or screen objects. The common denominator among these widgets is that the user can click on them or press the enter/return key when the focus is on them to initiate some action (e.g., the user "selects" a menu item and a dialog box appears).

Selectable Text and Graphics

There are several ways to present information (e.g., words or graphics) which have links to more information (e.g., hyperlinks). The method used to show these links in PCMAS II (F/A-18) and GDES IMIS is a rectangular box around certain selectable items (e.g., graphic captions and block diagrams). The primary problem associated with this implementation is how and when to show the user that the item is selectable (i.e., When should the rectangular box become visible?). The box cannot be present all the time; for example, if pieces of text in a paragraph are selectable, the box will interfere with the readability of the text.

However, with the onset of icon bars and context-sensitive actuation of menu items, a method of link marking, first introduced by Glushko (1990), can be implemented. In a modified version of Glushko's concept, appropriate icons become available as the user moves the cursor or pointer around the screen (over the selectable items). This shows the user what additional information is available for different types of information presented on the screen. This method has not been implemented on any IMIS systems, however, implementation of this type of identifying strategy is practicable.

Autoselect Radio Buttons

Aside from menus of lists, listed items can be designed to allow a single choice or multiple choices. A single choice occurs when the user is required to pick only one condition which meets the criteria. For example, the user needs to choose whether continuity exists between two points (i.e., a "Yes" or "No" answer). Radio buttons are typically used to show activation of the item "selected." A multiple choice occurs when the user is required to pick all the conditions that meet the criteria. For example, the user needs to identify whether the condition exists for the front, back, or both seats of the F-16 aircraft. Check boxes are typically used for this type of choice to show activation of all of the "selected" items.

When a single choice (e.g., radio button) is used in the user interface, the user should be able to move the cursor with the arrow keys over the desired item and the focus should automatically move with the cursor (just like menus). This design feature reduces the number of keystrokes required of the user. When this feature was added to the F/A-18 PMA for some operational checkouts, as many as 20 keystrokes were eliminated by incorporating this "autoselect" capability. In the GDES system, the autoselect feature was added for most user interface single-choice options. In the IPS, autoselect was implemented for all single-choice options.

Menus

Several issues which must be addressed during menu design include the following:

- How should the menu bar be activated if it is not always visible (e.g., due to space limitations)? Should the menu bar toggle on and off? This might be a consideration if the screen is small. In the F/A-18 and GDES systems, a menu key activates the main menu. In the IPS system, the menu is available between procedures but not while the user is in the middle of a procedure.
- When can the menu be accessed, and what items can be accessed (i.e., which ones need to be grayed out and when do they need to be grayed out)? This varies and will continue to vary with every application.
- How should information be organized on the menu bar (e.g., frequency of use, criticality of use, alphabetically, and so forth)? This order has been used for all IMIS designs, but determining frequency, criticality, and the like should be done systematically.
- Should different jobs (e.g., technician versus a supervisor) have different menus, or should they just have restricted access to certain menu items? The GDES IMIS system was the first to have different types of users accessing functions on the system. It simply restricts access to certain menu items. This was well accepted, and the design lends itself to better transfer training when a user is promoted (i.e., they know where some of the functions are located on the menu bar).

- What should specific menu items be named? This should be systematically determined. However, names should not necessarily be based on what the functions are called currently, but rather on what they should be named.

When menu functionality is required outside the menu bar, two widgets may be used: (1) single-choice options (radio buttons or listers) with a confirmation, and (2) pop-up menus. In many instances, these two widgets appear to provide the same functionality; however, there are some occasions where one widget should be implemented rather than the other. Identification of the criteria to be used for these different occasions was necessary in IMIS design and development efforts.

Identification of the criteria to be used in differentiating between when to use single-choice options (radio buttons or listers) with a confirmation and when to use pop-up menus involved several steps. The first step was to research existing literature on when to use each widget. The Motif Style Guide (Open Software Foundation, 1989) was used as the primary baseline. From this baseline, additional criteria were added to assist in identifying when to use each type of widget. This list is intended to be an aid in the GDES IMIS design process but is not an all-inclusive list of criteria. The following criteria resulted from this analysis.

Single Choice Options with Confirmation	Pop-Up Menu
No more than six items (for radio buttons only)	No more than nine items
More than nine items (for listers only)	
More space available	Little space available
Access to other dialogs required	If number of options changes from time to time
Confirmation of choice required	

Feedback

Feedback to the user refers to acknowledgment that the system has received input from the user and either is working on an answer or has no response to give (in either case feedback is required). Issues involved with feedback include cues (e.g., visual or auditory) and the time required to provide the cues. In accordance with research on screen response times, responses to key presses should be less than 0.1 second for visual feedback on the screen (Wampler et al., 1993). If the key press naturally results in some visual feedback, no additional cues are necessary. If feedback is not immediate (less than 0.1 second), the pointer shape should change (e.g., a watch icon will be displayed). If a key is inoperative, there should be some visual indication that the key is inoperative. When key presses display a new screen, the image should be refreshed immediately. If response time is greater than five seconds, a progress indicator should be displayed (IBM Corporation, 1991). Visual cues have been used throughout the design process because of high noise levels in flight line maintenance environments.

The goals of each IMIS application, including those in Phase I, have been to provide response times of less than two seconds for most screens and ten seconds for complex processes (e.g., running a diagnostic module). However, both goals have only been attained in the IPS. The F/A-18 presentation system provided response times of less than two seconds due to a "look ahead" capability in the system. That is, as the user views the currently presented screen, the system prepares the next screen for presentation. The IPS did not require this "look ahead" capability to present the technical data information in the time required because of innovative data structures. Additionally, the diagnostic module in the IPS also performed within the ten second limit and frequently performed well below this limit.

When system response times are greater than a few seconds, the user should be provided a progress indicator. Progress indicators should be displayed to the user when the computer will take "some period of time" to generate and/or draw the next screen on the display. The question posed was: "What is that period of time?" An IBM publication (1991) states that processes which require more than five seconds to finish should display some type of indicator. The actual progress indicator display can be a percent complete, "4 out of 10 files copied" type display, or a scale showing the status.

The other related topic was whether some indication is required for operations of five seconds or less. In this case, having the pointer change to a "wait" icon would be beneficial. Also, this icon should have some movement associated with it to indicate to the user that something is happening. For example, the icon could be a watch and the hands on the watch could move. When this visual cue is used, it should be designed so that the user cannot move the icon off the screen (i.e., it should be visible to the user at all times). Both the F/A-18 and GDES systems successfully implemented the wait icon for most of the operations which require greater than two seconds to perform; however, it was not made permanently visible. For operations requiring more than five seconds to perform, the IPS implements a permanently visible progress indicator.

SOFTWARE USER INTERFACE AND TECHNICAL DATA PRESENTATION — LESSONS LEARNED

Presentation of technical data can be grouped into two main areas. The first is the presentation of technical order data (e.g., maintenance procedures, parts information, troubleshooting information, and descriptive or theory information). The second is the presentation of technical data which requires additional information or confirmation of validity from the user (e.g., dialog-type information). Within the context of the software user interface, each group will be discussed independently. Within each group, interface issues will be addressed in terms of a checklist of considerations. See Appendix A for example screens.

Presentation of Technical Order Data

The following subsections provide design recommendations based on the F/A-18, GDES, and other IMIS (F-22, F-16, etc.) presentation systems. Identification of how each application has implemented input conditions and steps is less important than the justifications for the resulting design recommendations. Therefore, the following subsections provide recommendations for design along with their respective justifications. Note, however, that many different designs have been tried prior to these resulting recommendations.

Group Procedure Input Conditions Together

Grouping input conditions on a screen (or series of screens) assists in giving the status of a task (and nested task) and an *overall* notion of what needs to be accomplished prior to beginning the primary task. An effective interface design can result in fewer required keystrokes (e.g., after checking off a required condition, the input focus moves automatically to the next unchecked condition). Throughout the IMIS development process, several methods have been used to display input conditions — including separate and grouped displays. The Human Computer Interface Specification (HCIS) (Wampler et al., 1993) outlines a method which combines the benefits of each method into an efficient display methodology (see Appendix A for examples). This method was used exclusively in the IPS.

Within specific input conditions, there are some formatting issues which assist in grouping information. Grouping information aids users in locating information and assimilating more of the information presented on the screen. Aside from presenting the title of the information (e.g., INPUT CONDITIONS), each type of condition should be separately labeled (e.g., CONSUMABLES). The consumables are best displayed in a tabular format with each category represented in columns.

Warnings, Cautions, and Notes

In any presentation environment (paper or electronic), it is often critical that the technician be *alerted* to the present condition; however, getting the user's attention is different depending on the environment. In a computer-based environment, attention-getting displays can be readily developed, but paper manuals have limited methods available to catch the attention of the reader. Additionally, the contrast of characters to background is much better in paper than in electronic environments. Therefore, even if the method of presentation is exactly the same, some of the attention-getting characteristics provided by good contrast are not as effective in an electronic environment.

In efforts to attract the user's attention to the alerts, various icons have been used, distinguishing borders have been used among the alert types, and explicit acknowledgments are used for each alert. For example, among the IMIS displays implemented throughout development, alerts have been modal dialogs (not allowing any user input until the dialog is acknowledged) appearing prior to the display of subsequent information.

Alerts presented prior to the beginning of the task (e.g., procedural alerts) should be distinguished from the alerts that apply to only one step (e.g., step alerts). Additionally, and especially if presented as dialogs, all alerts should be available for review after initial display. The IPS IMIS implementation incorporates an icon approach to this requirement. Because many "windows" applications now use an icon bar for "quick access" to information, recent IMIS designs have incorporated an area at the top of the screen (under the Title Bar) for procedural icons. The user can tab to this area and select the icon (e.g., press return) to redisplay the procedural icon.

Warnings, cautions, and notes which apply to the entire task need to be shown prior to beginning the task. Exact placement of the alert has generally been displayed after required conditions are met. Alerts which pertain to a particular step should be displayed adjacent to the step to which they apply. The IPS implementation provides space above steps for the procedural icons and space to the left of steps for the step icons. Warnings, cautions, and notes which apply to the entire task are shown prior to beginning the task. Finally, Warnings, cautions, and notes applying to a particular step are displayed in a dialog box if the step is highlighted as the currently active step.

To conserve room on the display screen, when multiple alerts pertain to a step or a procedure, the icons should be stacked on top of one another with the most important (e.g., warning icon) on the top. Upon selection of the icon, the user would view all icons in succession starting with the most important (e.g., warnings, then cautions, then notes). If there are several alerts within one type (e.g., two warnings), the warnings are displayed in the order they are authored.

A design concept under consideration is to allow the user to choose specific alerts to be redisplayed. This could be accomplished through display of a selector on each alert screen. This selector would show the total number of alerts to be displayed, as well as the number of the current alert being displayed. The user could then explicitly choose the alert desired and that alert would be redisplayed.

Presentation of Steps

A point paper was provided to Armstrong Laboratory from the F-22 Engine Support Systems Data Manager (1992). This paper addressed a philosophy of the IMIS systems personnel to present information in a step-at-a-time manner. The purpose of the paper was to identify that a screen-at-a-time approach could provide a better interface for maintenance technicians than a one-step-at-a-time approach. The point paper was reviewed to identify any covert reasons this approach could not be used in an F-22 IMIS environment. The following comments were provided to Armstrong Laboratory for further review.

It appears that a proposed screen-at-a-time approach will work; however, some design features will need to be employed to meet GCSFUI requirements (Department of Defense, 1992b) and usability requirements.

Requirements would include the need for a NEXT function (Department of Defense, 1992b) key, a BACK function key, a TAB function key, a BACKTAB function key, arrow key functions, and a pointer function.

The NEXT and BACK functions would be used to move between screens (as they currently do); however, in this new application, pressing the NEXT function key would display a new set of steps.

The TAB and BACKTAB function keys would move the cursor among tab groups on the screen (e.g., text pane, graphic pane, icon area, etc.). The text pane on the screen would act as the primary tab group and would hold a "key" as to which graphic is displayed at any given time. For example, the key would be the step which is currently active. The graphic displayed would correspond to the step currently active. The TAB key would simply move from the currently active step to the currently active graphic.

The arrow keys and pointer would be used to move the cursor within the tab group (e.g., from step to step). There remains a question here about how to handle selectable words within a step; however, making the step number selectable might solve this dilemma. In other words, the user could move the cursor (via arrow keys or point-and-select) onto the step and, subsequently, the graphic would change to match the step.

The user could simply move the cursor down the content region to the last step displayed, press the down arrow again (through the steps presented on the screen to the bottom step), and the next set of steps would be displayed. Again, this would help promote the continuing task sequence reinforcement aspect identified in the point paper. If, on the other hand, the user presses the NEXT function key, a new set of steps would be displayed on the screen, thereby minimizing keystrokes.

In relation to the basic concept outlined in the point paper, the screen-at-a-time method seems reasonable and feasible — given the modifications identified above. As the user moves the cursor down the screen onto various steps (e.g., by pressing the down arrow key), the appropriate graphics are displayed; if the user does not need additional visual information (provided by the graphics), the step may simply be read. The steps, however, should be separated by appropriate white space (i.e., perceptibly more carriage returns between steps than between lines of continuous text). This white space increases the users' ability to keep their place when moving from line to line.

Presentation of Follow-On Conditions

Presentation of follow-on conditions and presentation of required conditions raise many of the same issues. For example, follow-on conditions should be presented all at once (a full screen). Fewer keystrokes are required if they are presented all at one time. The user should be provided three options: (1) see the procedure to complete the follow-on task, (2) check-off the follow-on task as having already been completed, or (3) postpone the follow-on task for completion at a later time.

Graphics

Presentation of graphics has a whole range of pertinent topics associated with it. This discussion is intended to identify these topics at a high level.

Graphics associated with a step need to be displayed as the appropriate step is highlighted. The graphic displays the appropriate call-outs for the highlighted step (without requiring scrolling). White space (i.e., border areas without any information) should be minimized. These modifications can be made during authoring of the technical data or at display time. When presented on a computer screen, graphics used in presentation of technical data should contain much less detail than graphics presented on paper. This change needs to be made during authoring.

Presentation of wiring diagram graphics should include identification of bulkheads, names of line-replaceable units (LRUs), plug/jack labels, and pin/socket numbers. Adding this type of information to wiring diagrams will aid technicians in readily locating the wire that needs to be tested.

Presentation of Other Screen Regions in Technical Order Data

Message Lines. Message lines should be used throughout a technical data presentation to show the user how to move to the next piece of pertinent information (i.e., the next screen of information).

Softkeys. The softkeys, generally presented at the bottom of the screen, allow quick access to pertinent menu bar actions through a single key press (e.g., "F1_OK"). The pertinent issue for softkeys is identification of the appropriate softkeys for the various types of screens. A matrix of screen types and potential softkey labels is recommended for designing and implementing these functions. The matrix should result in a set of softkey labels given the limited number of types of screens. It should be noted, however, that Carney and Quinto (1993) determined that use of softkeys should be minimized in future designs because users are unfamiliar with these keys.

System Subsystem Subassembly (SSS) Browser. There are two overall functions of the system subsystem subassembly (SSS) browser. The first is to allow users to view data for any system without recording that action as having been performed. For example, users may want to view a procedure before performing it on the aircraft. The browser would allow this function. The second function is to allow users to access data anywhere in the system and to record that actions have been performed. For example, the user may decide to perform a task (on the aircraft) which is not recommended by a diagnostics aid. The SSS browser would allow the user to choose any desired procedure from a lister.

To accommodate the functionality requirements of the SSS browser, it is recommended that several display viewports be displayed simultaneously. For example, upon first entering the SSS browser, one viewport would provide a choice list for choosing procedures, theory, parts, and so forth; one would be the systems, subsystems, subassemblies list; and another viewport would be available for listing data. Note that upon first entering this lister, the currently active choice should be the system or subsystem currently being worked by the user (e.g., if the Head-Up Display [HUD] is being replaced, the HUD system would be highlighted in the lister). After the user verifies or changes the desired system, the data type (e.g., procedures) can be selected. Upon choosing the appropriate data from the list (e.g., the specific procedure to be performed), the user could choose (off the push buttons) to either view or browse the procedure (actions would not be recorded) or to perform the procedure (actions would be recorded in a log file to be used in diagnostics or forms completion activities).

The key to providing this capability is ensuring that the data are appropriately "tagged" in the underlying database. If data tagging schemes do not include any hierarchical structuring of systems, subsystems, and subassemblies, this type of presentation is not possible.

REFERENCES

Alden, D.G., Daniels, R.W., & Kanarick, A.F. (1972). Keyboard design and operations: A review of the major issues. *Human Factors, 14*(4), 275-293.

Applied Science Associates, Inc. (1990). *Edwards evaluation (EE) report* (Rough Draft) Butler, PA: General Dynamics Electronics Division.

Boff, K., & Lincoln, J.E. (1988). *Engineering data compendium: Human perception and performance.* Wright-Patterson AFB, OH: AAMRL/HE.

Carney, L.A., & Quinto, R.A. (1993). *Evaluation of access/navigational features of a graphical user interface installed on a portable maintenance aid.* Unpublished master's thesis, Air Force Institute of Technology, Wright-Patterson AFB, OH.

Cushman, W.H. (1986). Reading from microfiche, a VDT, and the printed page: Subjective fatigue and performance. *Human Factors, 28*(1), 63-73.

Department of Defense. (1992a). *Military specification: Database, revisable: Interactive electronic technical manuals, for the support of* (MIL-D-87269). Philadelphia, PA: Naval Publishing and Printing Service Office.

Department of Defense. (1992b). *Military specification: Manuals, interactive electronic technical: General content, style, format, and user-interaction requirements* (MIL-M-87268). Philadelphia, PA: Naval Publishing and Printing Service Office.

Department of Defense. (1985, March 7). *Military Standard* (MIL-S-40022E). Philadelphia, PA: Naval Publications and Forms Center.

Department of Defense. (1989, March 14). *Military Standard: Human engineering design criteria for military systems, equipment and facilities* (MIL-STD-1472D). Philadelphia, PA: Naval Publications and Forms Center.

Epson America, Inc. (1991, February). *LCD module for 640 x 480 Dots* (Specification #EG9007D-NS). OEM Products Division.

F-22 Engine Support Systems Data Manager. (1992). *F-22 support systems data.* Unpublished point paper, Wright-Patterson AFB, OH.

Galitz, W. (1985). *Handbook of screen format design* (Revised Edition). Wellesley Hills, MA: Information Sciences, Inc.

General Dynamics Electronics Division. (1990). *System segment specification for the integrated maintenance information system (IMIS) phase II* (Document No. 9001608A, Contract No. F33615-88-C-0024). San Diego, CA: author.

Glushko, R.J. (1990). *Hypertext: Prospects and problems for crew system design.* Norcross, GA: Search Technology.

Gould, J.D., Greene, S.L., Boies, S.J., Meluson, A., & Rasamny M. (1990). Using a touchscreen for simple tasks. *Interacting with Computers*, *2*(1), 59-74.

Greenstein, J.S., & Arnaut, L.Y. (1988). Human factors aspects of manual computer input devices. In M. Helander (Ed.), *Handbook of Human-Computer Interaction* (pp. 495- 519). Amsterdam: North-Holland.

Greenstein, J.S., & Arnaut, L.Y. (1987). Human factors aspects of manual computer input devices. In G. Salvendy (Ed.), *Handbook of human factors* (pp. 1450-1489). New York: John Wiley and Sons.

Hirsch, R.S. (1970). Effects of standard versus alphabetical keyboard formats on typing performance. *Journal of Applied Psychology*, *54*(6), 484-490.

Houghton Mifflin Company. (1982). *American heritage dictionary* (2nd College Edition). Boston, MA: author.

Human Factors Society, Inc. (1988). *American national standard for human factors engineering of visual display terminal workstations* (ANSI/HFS 100-1988). Santa Monica, CA: Author.

IBM Corporation. (1991). *Common user access advanced interface design reference.* Cary, NC: IBM Corporation.

Johnson, R.C. (1993). *Point paper on IMIS.* WPAFB, OH: author.

Karat, J., McDonald, C., & Anderson, M. (1986). A comparison of selection techniques: Touch panel, mouse, and keyboard. *Journal Man-Machine Studies*, *25*, 73-88.

Kinkead, R. (1975). Typing speed, keying rates, and optimal keyboard layouts. In *Proceedings of the Human Factors Society - 19th Annual Meeting* (pp. 159-161). Santa Monica, CA: Human Factors Society.

Kyocera. (1991, February). *Type: KI6448FSHT-FW (HS)* (Specification #S7FWF0HG2C06001).

Link, W.R., Murphy, J.E., Carlson, E.N., Thomas, D.L., Brown, J., & Joyce, R.P. (1990). *Integrated maintenance information system diagnostic demonstration* (Report No. AFHRL-TR-90-41). Wright-Patterson AFB, OH: Logistics and Human Factors Division.

McCormick, E.J., & Sanders, M.S. (1982). *Human factors in engineering and design* (5th Edition). New York: McGraw-Hill Book Co.

Michaels, S.E. (1971). QWERTY versus alphabetic keyboards as a function of typing skill. *Human Factors, 13*(5), 419-426.

Moorman, L.L., & Quill, L.L. (1991). *Common user interface specification (CUIS)* Dayton, OH: Eagle Technology, Inc.

Morrissey, S.J., & Chu, R.W. (1988). Legibility of video display units during off-angle viewing. *Behaviour and Information Technology*, *7*(1), 3-9.

Norman, D.A., & Fisher, D. (1982). Why alphabetic keyboards are not easy to use: Keyboard layout doesn't much matter. *Human Factors*, *24*(5), 509-519.

Oborne, D.J., & Holton, D. (1988). Reading from screen versus paper: There is no difference. *International Journal of Man-Machine Studies, 28*, 1-9.

Open Software Foundation. (1989). *OSF/Motif style guide* (Rev. 1.0). Cambridge, MA: Author.

Quill, L.L. (1994). *Design considerations for an on-screen keyboard.* Unpublished master's thesis, University of Dayton, OH.

Quill, L.L. (1992a). *Deficiencies and recommendations summary for the F/A-18 portable maintenance aid* (Version 2.0, Contract No. DLA900-88-D-0393). Dayton, OH: University of Dayton Research Institute.

Quill, L.L. (1992b). *IMIS design support* (Contract No. DLA900-88-D-0393). Dayton, OH: University of Dayton Research Institute.

Quill, L.L., & Biers, D.W. (1993). On-screen keyboards: Which arrangements should be used? In *Proceedings of the Human Factors and Ergonomics Society 37th annual meeting* (pp. 1142-1146). Santa Monica, CA: Human Factors Society.

Quill, L.L., Wynkoop, C.W., & Wampler, J. (1992). F/A-18 IMIS user and developer design impacts. In *CALS Expo '92 Proceedings* (pp. AP28-AP35). San Diego, CA: CALS/CE Industry Steering Group.

Salvendy, G. (1987). *Handbook of human factors*. New York: John Wiley & Sons.

Shneiderman, B. (1992). *Designing the user interface: Strategies for effective human-computer interface*. Reading, MA: Addison-Wesley Publishing Company.

Streff, G.E., & Gundel, R.H. (1992). *Comparison of four-cursor buttons versus joystick to access computerized technical information from an integrated maintenance information system*. Unpublished master's thesis, Air Force Institute of Technology, Wright-Patterson AFB, OH.

Thomas, D.L., & Clay, J.D. (1988). *Computer-based maintenance aids for technicians: Project final report* (Report No. AFHRL-TR-87-44). Brooks AFB, TX: Air Force Human Resources Laboratory (HQ AFHRL).

Uphaus, J.A., Jr., Barthelemy, K., & Reising, J.M. (1990). Improve character readability in spite of pixel failures - A better font. *Proceedings of the IEEE National Aerospace and Electronics Conference, 1,* 278-283. (*From NASA - RECON,* 1992, Abstract No. 91A30884).

Van Cott, H.P., & Kinkade, R.G. (Eds.). (1972). *Human engineering guide to equipment design.* Washington, DC: U.S. Government Printing Office.

Wampler, J.L., Gunning, D.R., Wynkoop, C.E., Quill, L.L., & Moorman, L.L. (1993). *Human computer interface specifications (HCIS) for the integrated maintenance information system (IMIS* Tech. Report AL/HR-TP-1993-0035). Wright-Patterson AFB, OH: OL-AL/HRGO.

GLOSSARY, ACRONYMS, AND ABBREVIATIONS

AC	Alternating Current
AFB	Air Force Base
AFIT	Air Force Institute of Technology
AL	Armstrong Laboratory
AL/HRG	Armstrong Laboratory, Logistics Research Division
ANSI	American National Standard Institute
Autorepeat	The function that makes the activation of a depressed key duplicate over and over.
Autoselect	Screen regions at first display that require user input be highlighted and ready for user input of acceptance. This feature minimizes keystrokes.
Backlight	A light which illuminates behind the screen region. The backlight allows the user to see the screen in dark environments and increases screen contrast.
CAMS	Core Automated Maintenance System
CMAS	Computerized Maintenance Aiding System
FOD	Foreign Object Damage
GCSFUI	General Content, Style, Format, and User Interface
GDES	General Dynamics Electronics Systems
HCIS	Human Computer Interface Specification
HFS	Human Factors Society
IETM	Interactive Electronic Technical Manual
IMIS	Integrated Maintenance Information System
IPS	IETM Presentation System
Key flushing	When drawing an image on the screen takes longer than the time to input several key presses, the system will accept only one key press.
Keypad	The hardware keys associated with a Portable Maintenance Aid, usually a limited number of keys (as opposed to the full QWERTY keyboard).
Keytop	The area on the upper portion of a hardware key. This is the area where a user presses the key.
LCD	Liquid Crystal Display
Lister	A region on the screen that contains a listing of objects of similar type.
LRU	Line Replaceable Unit

GLOSSARY, ACRONYMS, AND ABBREVIATIONS (Continued)

MIL-STD	Military Standard
PC	Personal Computer
PCMAS	Portable Computer-Maintenance-Aiding System
PMA	Portable Maintenance Aid
Push-buttons	Areas on the screen region that can be clicked or activated. Activation of a push-button causes some action to occur (e.g., clicking on a Cancel push-button will cancel a dialog).
RF	Radio Frequency
Selectable	A screen region which can be highlighted by the user, then activated in some way.
Softkeys	Programmable keys which can change functionality depending on the screen content. The region on the screen which labels the function is termed the softkey region.
SSS	System Subsystem Subassembly
Thumb Knob	A knurled (concave) button that acts similarly to a joystick.
Trackball	A round input device. Although the device is stationary, the top portion of the ball can be rolled. Rolling the ball moves the pointer in a corresponding manner across the screen.
USAF	United States Air Force
Viewports	Screen regions in which various types of information can be displayed.

APPENDIX A: EXAMPLE SCREENS

RIGHT FORWARD MULTIPLEX MATRIX ASSEMBLY 9476A2, REMOVAL (94-76-02).

INPUT CONDITIONS

PERSONNEL RECOMMENDED: 1

SUPPORT EQUIPMENT:

Maintenance Platform, Type C-1 or equivalent

SUPPLIES (CONSUMABLES):

None

REFERENCE MATERIALS:

None

Press F1_Next for Required Conditions.

F1_Next | F4_Ref Matei | F7_Previous

RIGHT FORWARD MULTIPLEX MATRIX ASSEMBLY 9476A2, REMOVAL [94-76-02].

REQUIRED CONDITIONS

☒ **Aircraft safe for maintenance.**

☒ **PSP, 9461A5 removed.**

☒ **CADC, 3411A1 removed.**

Press F1_Next to begin the procedure, or F3_Completed to toggle checkmark.

F1_Next | F3_Comple | F2_Previous

REPLACE RT FWD MUX MAT ASSY, 9476A2

◇

SUB-TASK:

☒ **1. Remove right fwd mux matrix assembly, 9476A2**

Press F1_Next to begin the procedure, or F3_Completed to toggle checkmark.

F1_Next		F3_Comple		F7_Previous	

REPLACE RT FWD MUX MAT ASSY, 9476A2

◇

SUB-TASK:

☒ **2. Install right fwd mux matrix assembly, 9476A2**

Press F1_Next to begin the procedure, or F3_Completed to toggle checkmark.

F1_Next		F3_Comple		F7_Previous	

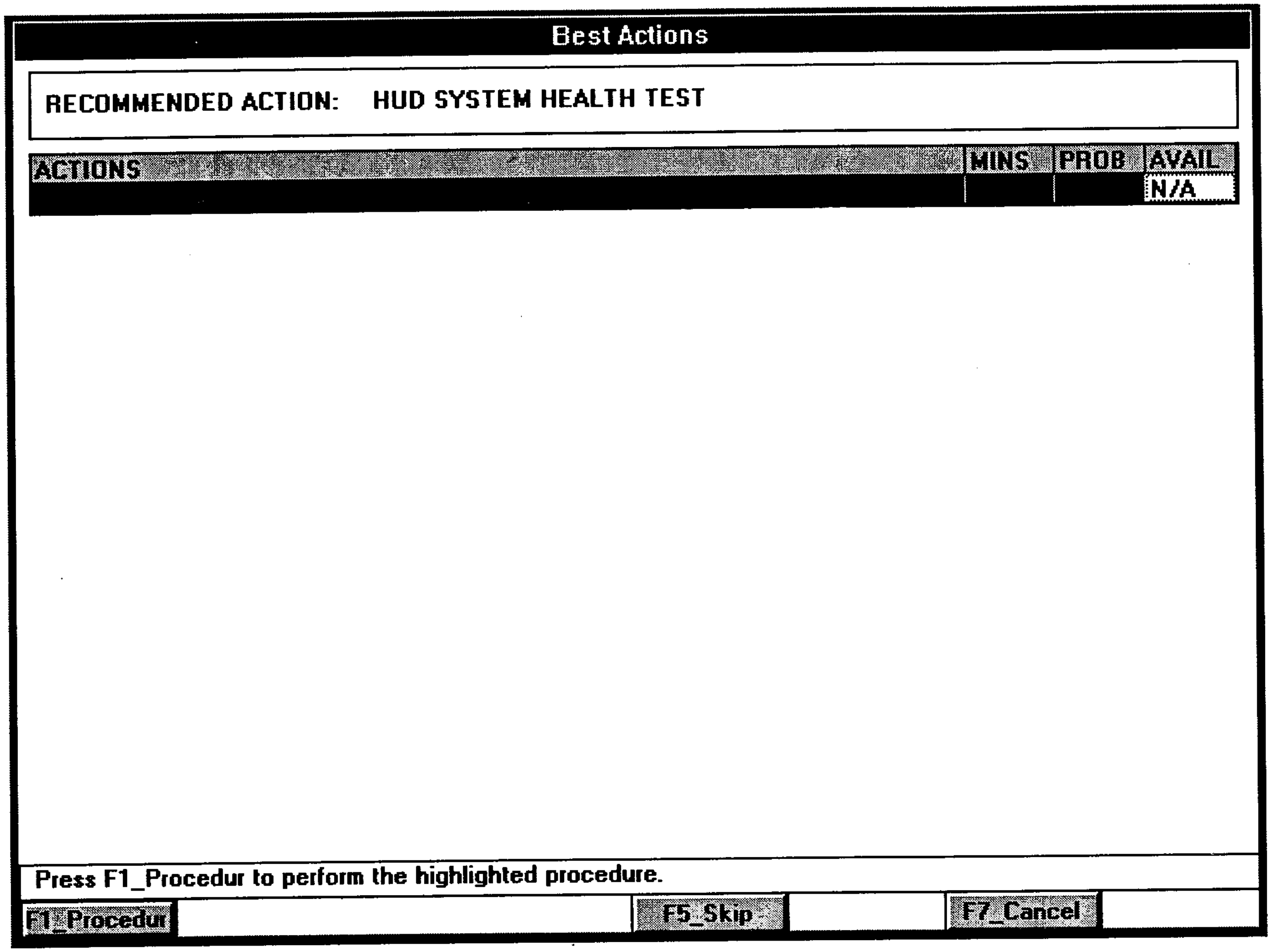
REPLACE RT FWD MUX MAT ASSY, 9476A2

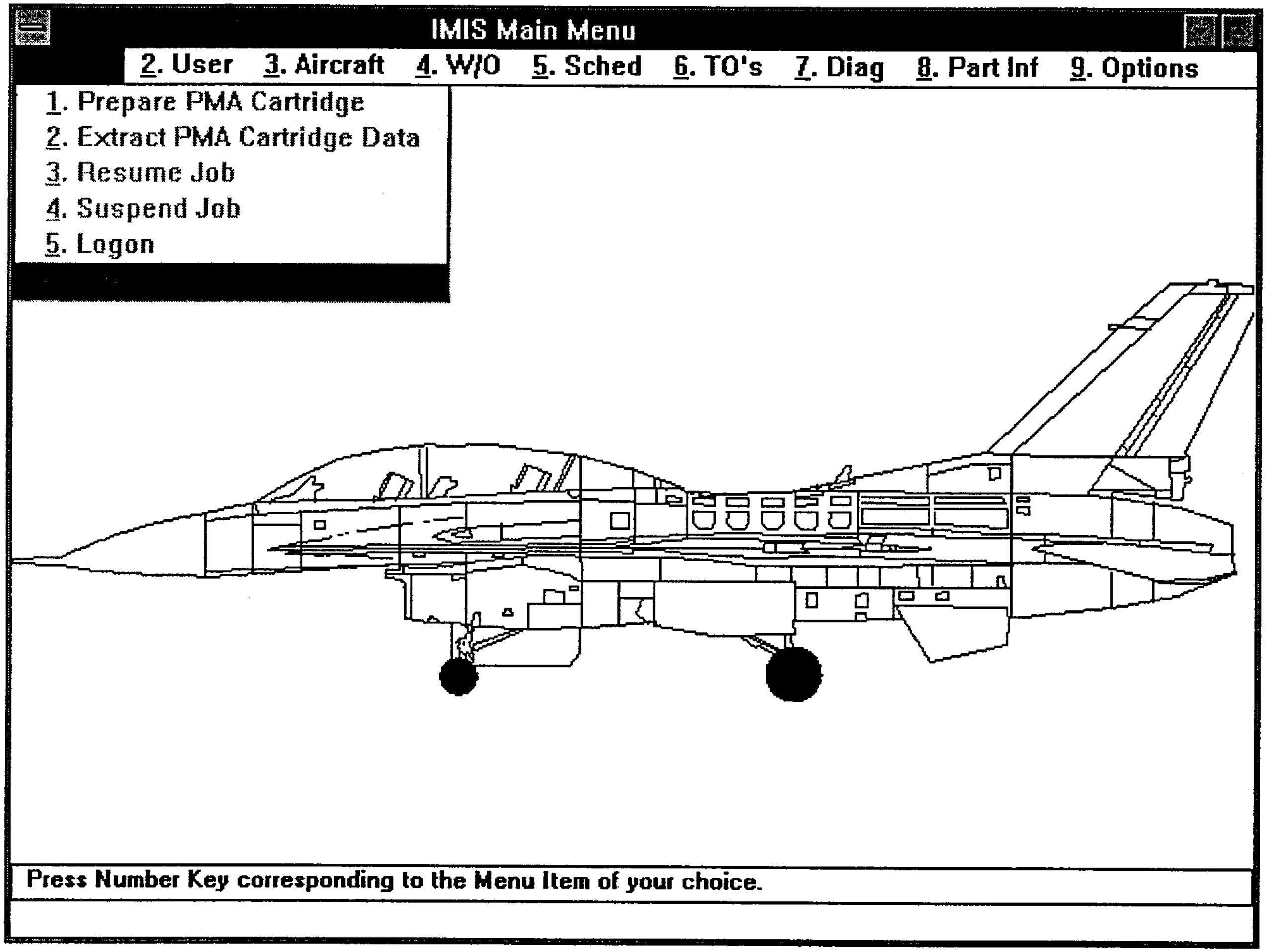
FOLLOW-ON TASKS

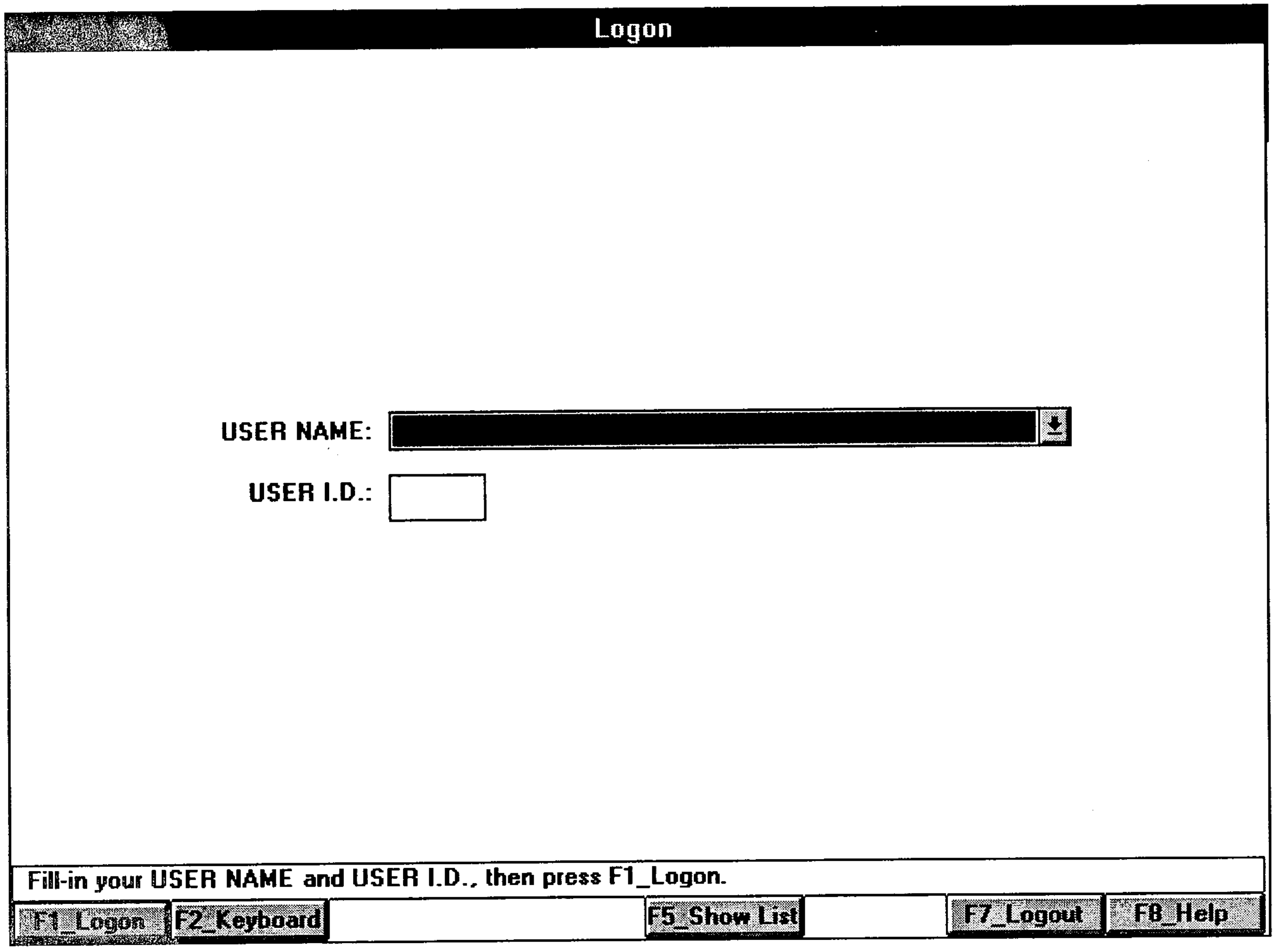
- [ ] **Perform INS alignment, operational checkout, and stored heading.**
- [ ] **Perform FCR operational checkout.**
- [ ] **Perform HUD operational checkout.**
- [ ] **Perform GAC operational checkout.**
- [ ] **Perform SMS confidence checkout.**
- [ ] **Install PSP, 9461A5.**
- [ ] **Install CADC, 3411A1.**
- [x] **Install right forward matrix assembly, 9476A2.**

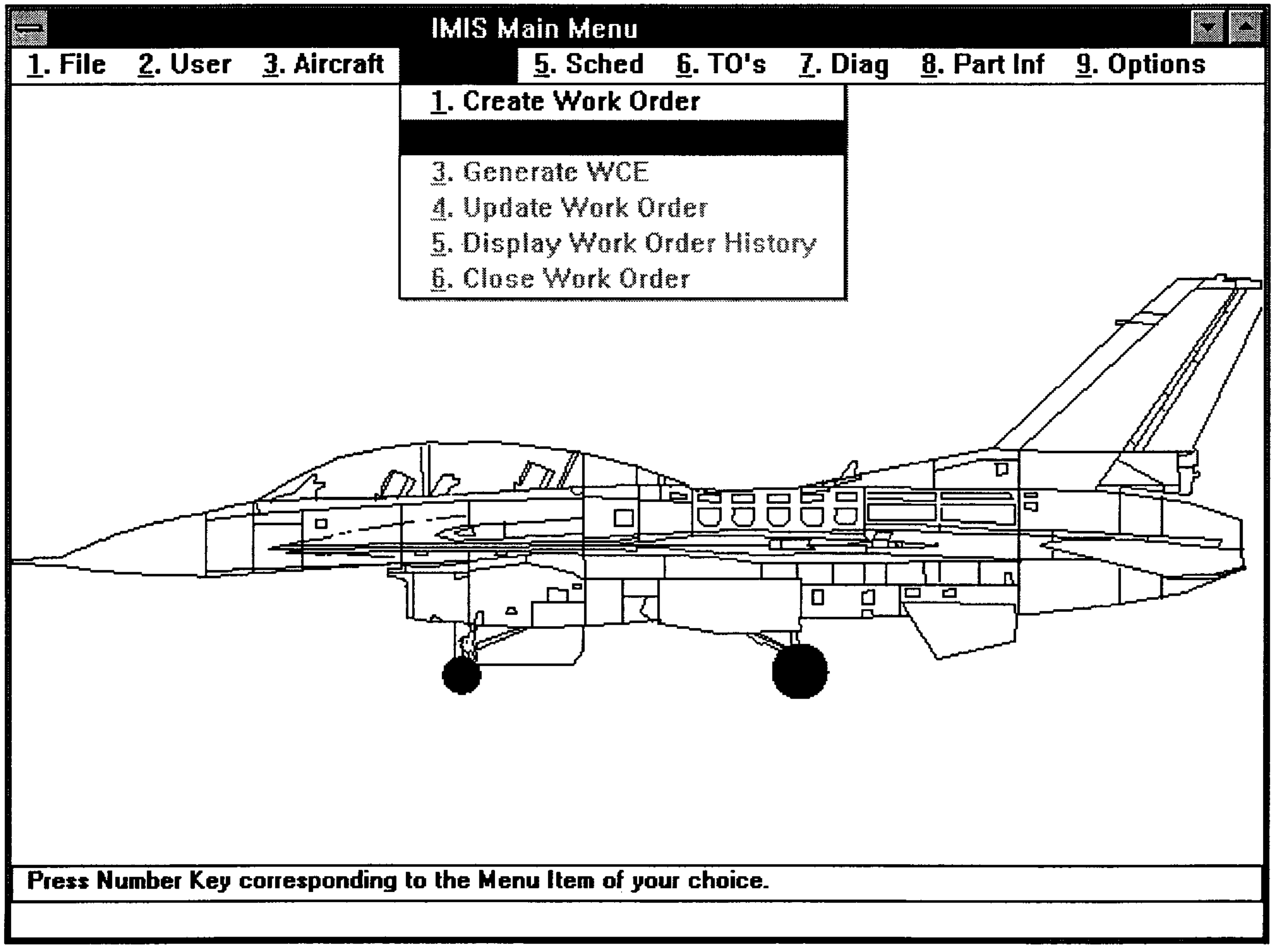
Press F1_Postpone for all tasks, F2_Access for Follow-On Tasks, or F3_Completed to toggle checkmark.

F1_Postpone | F2_Access | F3_Comple | F7_Previous


Best Actions
RECOMMENDED ACTION: HUD SYSTEM HEALTH TEST
ACTIONS
MINS
PROB
AVAIL
N/A
Press F1_Procedur to perform the highlighted procedure.
F1_Procedur
F5_Skip
F7_Cancel


IMIS Main Menu
2. User 3. Aircraft 4. W/O 5. Sched 6. TO's 7. Diag 8. Part Inf 9. Options
1. Prepare PMA Cartridge
2. Extract PMA Cartridge Data
3. Resume Job
4. Suspend Job
5. Logon
Press Number Key corresponding to the Menu Item of your choice.


Logon
USER NAME:
USER I.D.:
Fill-in your USER NAME and USER I.D., then press F1_Logon.
F1_Logon
F2_Keyboard
F5_Show List
F7_Logout
F8_Help


IMIS Main Menu
1. File
2. User
3. Aircraft
5. Sched
6. TO's
7. Diag
8. Part Inf
9. Options
1. Create Work Order
3. Generate WCE
4. Update Work Order
5. Display Work Order History
6. Close Work Order
Press Number Key corresponding to the Menu Item of your choice.

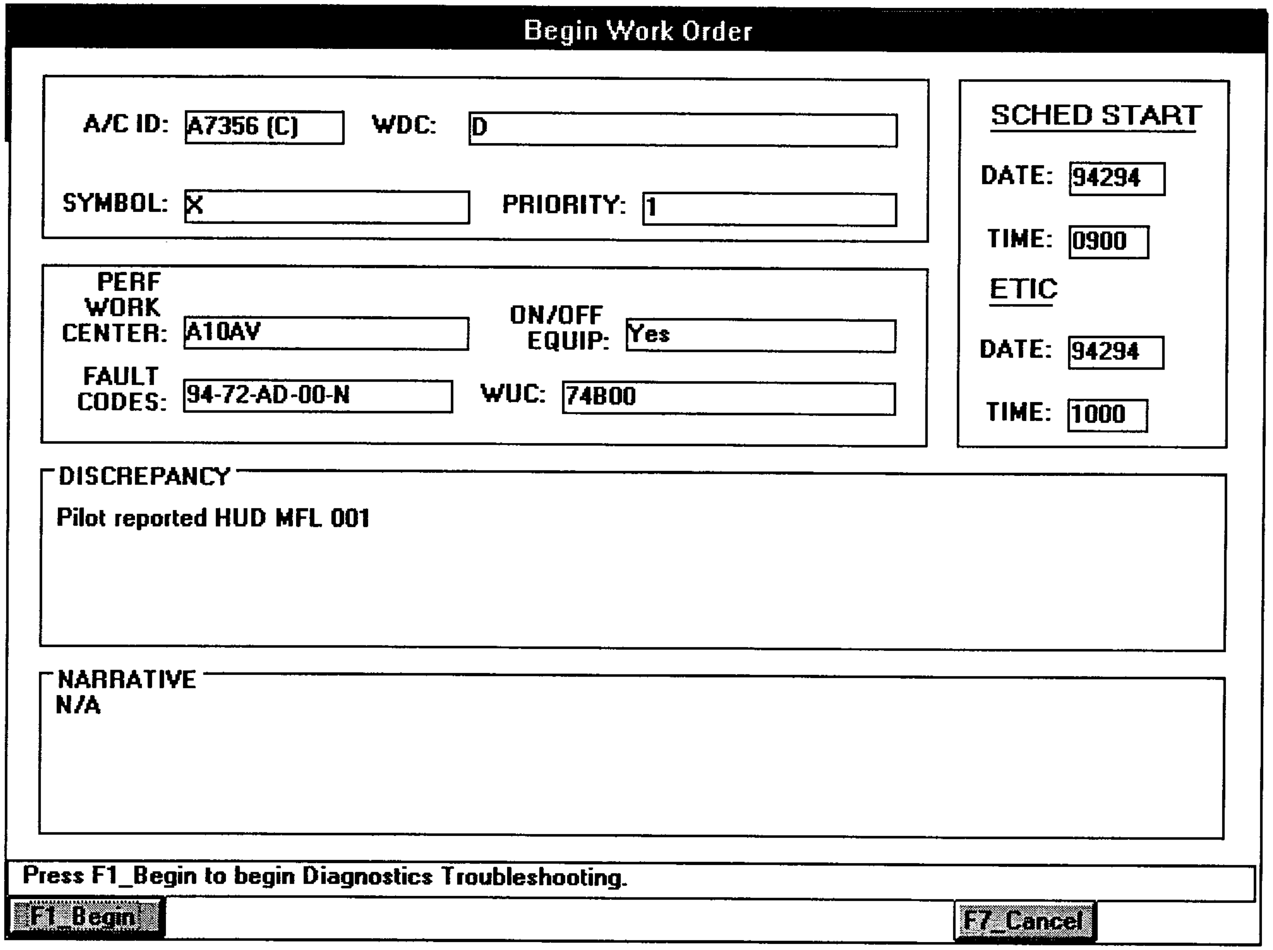
Begin Work Orders

[redacted]

942909401001	A7356 (C)	0900	94-61-AD-00-N	Pilot reported FCR MFL 001
942909402001	A7356 (C)	0900	94-61-AE-00-N	Pilot reported FCR MFL 002
[redacted]				
942909406001	A7356 (C)	0900	94-72-AE-00-N	Pilot reported HUD MFL 002
942909407001	A7356 (C)	0900	94-72-BM-00	Pilot reported HUD DEPR RET SW
942909408001	A7356 (C)	0900	94-72-BR-00	Pilot reported HUD TEST SW
942909409001	A7356 (C)	0900	94-63-AG-00	Pilot reported INS MFL 001

Highlight desired Work Order and press F1 to view the Work Order

F1_Work Ord   F7_Cancel



Begin Work Order

A/C ID:	A7356 (C)	WDC:	D
SYMBOL:	X	PRIORITY:	1
PERF WORK CENTER:	A10AV	ON/OFF EQUIP:	Yes
FAULT CODES:	94-72-AD-00-N	WUC:	74B00

SCHED START

DATE: 94294

TIME: 0900

ETIC

DATE: 94294

TIME: 1000

DISCREPANCY

Pilot reported HUD MFL 001

NARRATIVE

N/A

Press F1_Begin to begin Diagnostics Troubleshooting.

F1_Begin F7_Cancel

Fault Verification

RECOMMENDED ACTION: CHECK RT FWD MUX HUD DIGITAL DATA CKT

FAULT VERIFICATION TESTS	MINS	PROB	AVAIL
			N/A
2. HUD OPERATIONAL CHECKOUT (94-72-01)	10	N/A	N/A
3. HUD SYSTEM HEALTH TEST	17	N/A	N/A

Press F1_Procedur to perform the highlighted procedure.

F1_Procedur | F5_Skip | F7_Cancel

Best Actions

RECOMMENDED ACTION: CHECK RT FWD MUX HUD DIGITAL DATA CKT

ACTIONS	MINS	PROB	AVAIL
			N/A
2. CHECK RT FWD MUX TRANSFORMER	5		N/A
3. REPLACE HUD EU, 9472A1	25	.83	Yes
4. REPLACE RT FWD MUX MAT ASSY, 9476A2	34	.1	Yes
5. REPAIR WIRING, RT FWD MUX AND HUD EU	80	.07	Yes

Press F1_Procedur to perform the highlighted procedure.

F1_Procedur | F3_Tests | F4_Repairs | F7_Cancel

CHECK RT FWD MUX HUD DIGITAL DATA CKT

INPUT CONDITIONS

PERSONNEL RECOMMENDED: 1

SUPPORT EQUIPMENT:

None

SUPPLIES (CONSUMABLES):

None

REFERENCE MATERIALS:

None

Press F1_Next for Required Conditions.

F1_Next | F4_Ref Matel | F7_Previous

CHECK RT FWD MUX HUD DIGITAL DATA CKT

REQUIRED CONDITIONS

- [x] **Aircraft safe for maintenance.**
- [ ] **Door 1101 open.**
- [ ] **Connector 9472P1/1 disconnected.**
- [ ] **Connector 9476P1/2 connected.**

Press F2_Access for Required Condition, or F3_Completed to toggle checkmark.

F2_Access | F3_Comple | F7_Previous

OPEN DOOR 1101

INPUT CONDITIONS

PERSONNEL RECOMMENDED: 1

SUPPORT EQUIPMENT:

Maintence platform, Type B-4A or equivalent

SUPPLIES (CONSUMABLES):

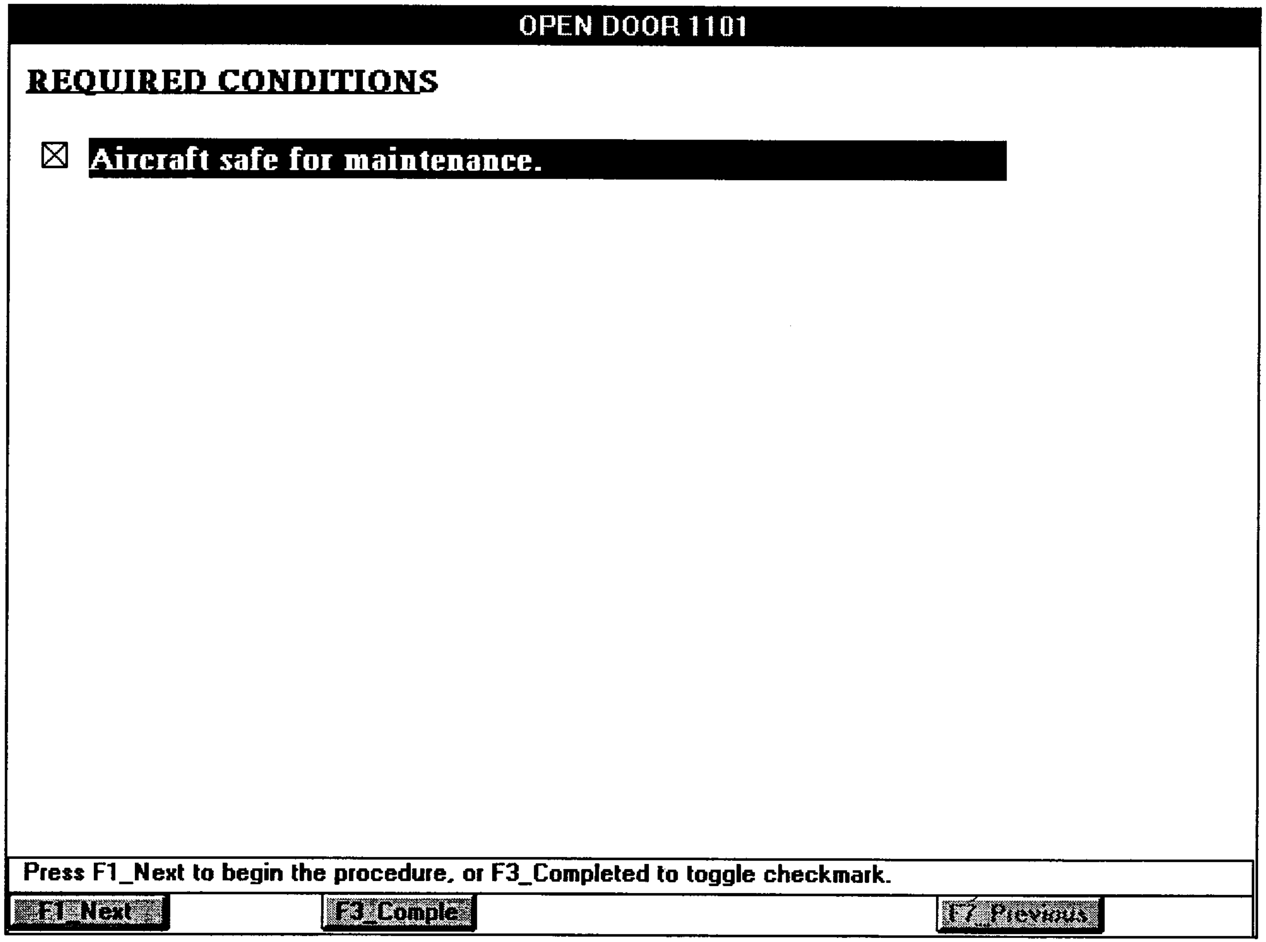
None

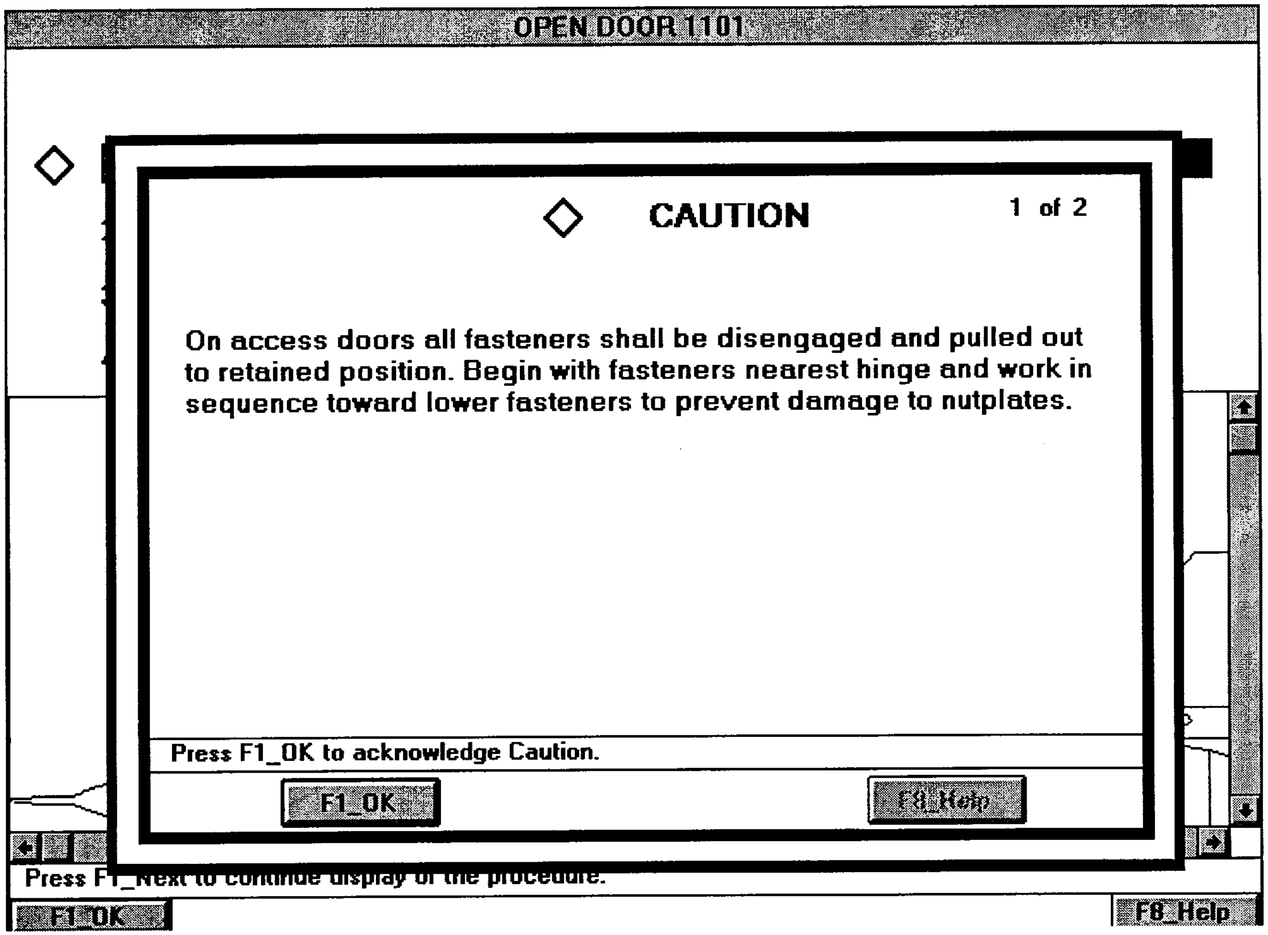
REFERENCE MATERIALS:

None

Press F1_Next for Required Conditions.

F1_Next | F4_Ref Mater | F7_Previous


OPEN DOOR 1101
REQUIRED CONDITIONS
☒ Aircraft safe for maintenance.
Press F1_Next to begin the procedure, or F3_Completed to toggle checkmark.
F1_Next
F3_Comple
F7_Previous


OPEN DOOR 1101
CAUTION
1 of 2
On access doors all fasteners shall be disengaged and pulled out to retained position. Begin with fasteners nearest hinge and work in sequence toward lower fasteners to prevent damage to nutplates.
Press F1_OK to acknowledge Caution.
F1_OK
F8_Help
Press F1_Next to continue display of the procedure.
F1_OK
F8_Help

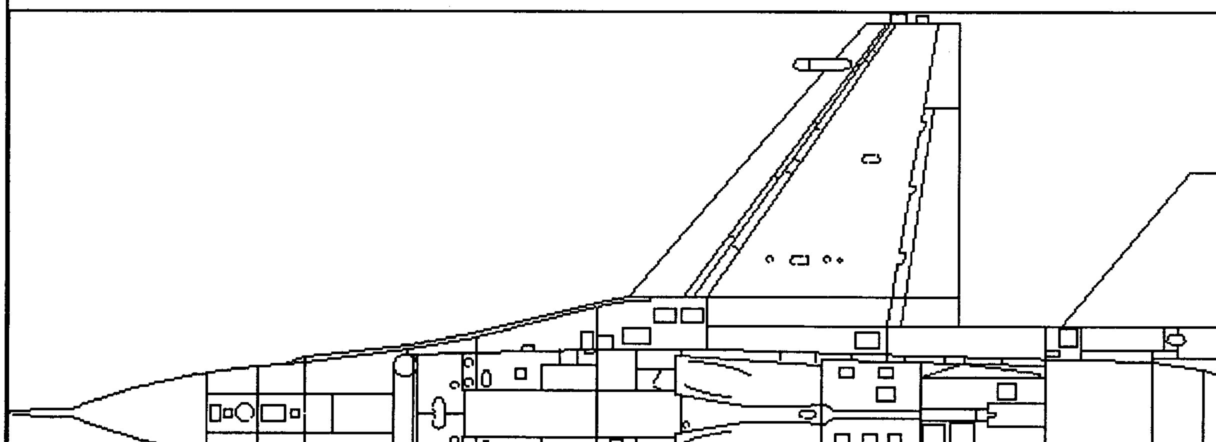
OPEN DOOR 1101

◇ 1. Disengage 14 fasteners.

2. Open door.

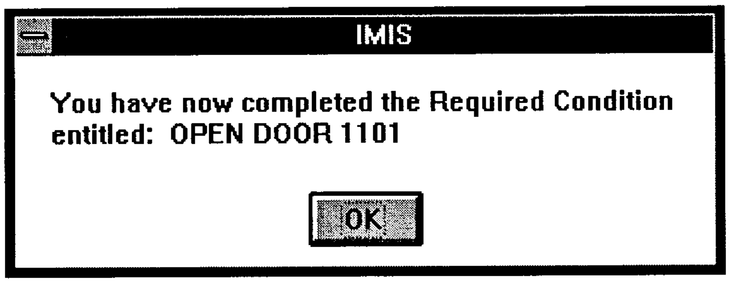
3. Position strut on support bracket.

4. Engage retainer pin.



Press F1_Next to continue display of the procedure.

F1_Next | F5_Graphic A | F7_Previous


IMIS
You have now completed the Required Condition entitled: OPEN DOOR 1101
OK

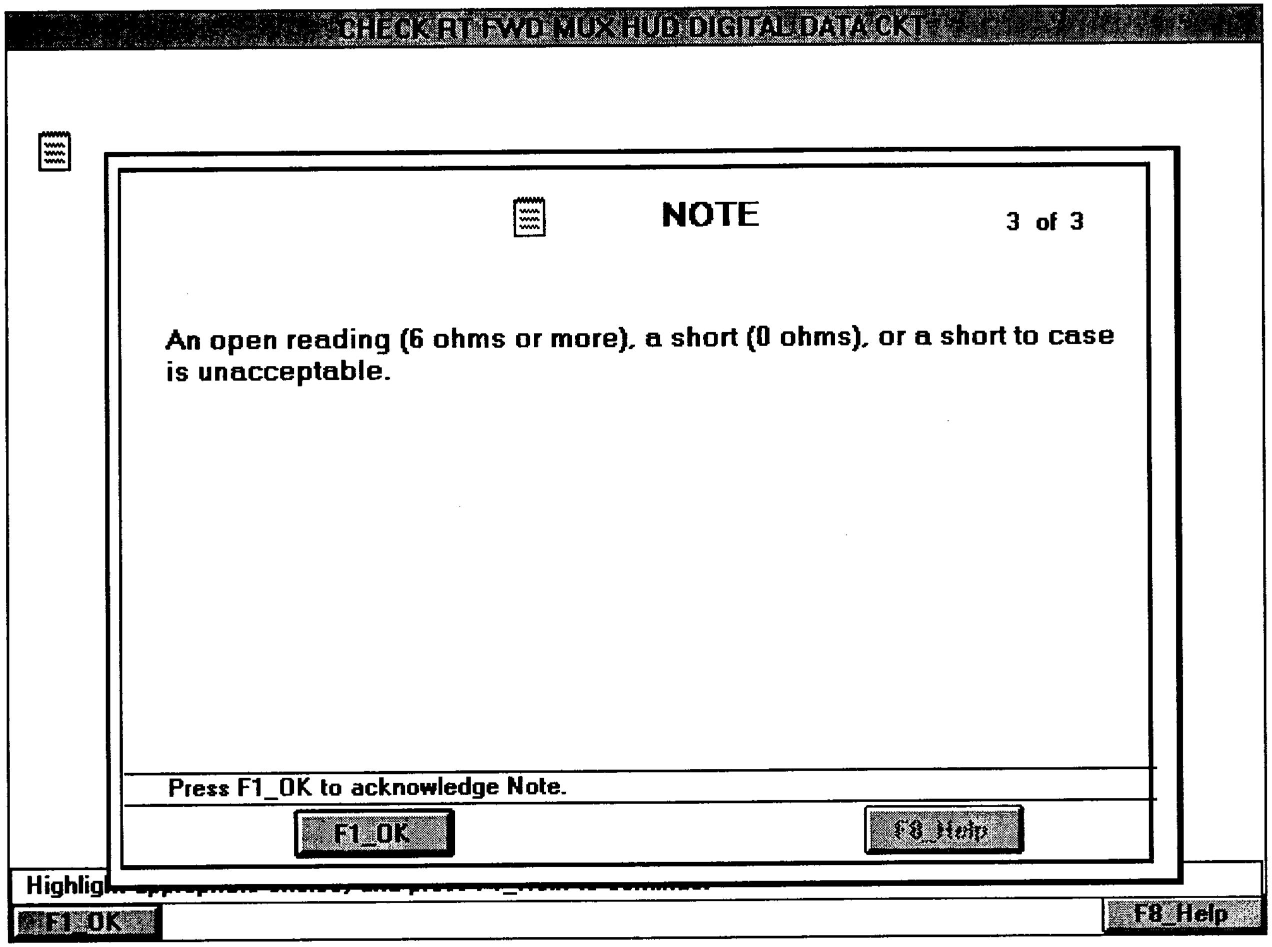
CHECK RT FWD MUX HUD DIGITAL DATA CKT

REQUIRED CONDITIONS

- ☒ **Aircraft safe for maintenance.**
- ☒ **Door 1101 open.**
- ☒ **Connector 9472P1/1 disconnected.**
- ☒ **Connector 9476P1/2 connected.**

Press F1_Next to begin the procedure, or F3_Completed to toggle checkmark.

F1_Next | F3_Comple | F7_Previous

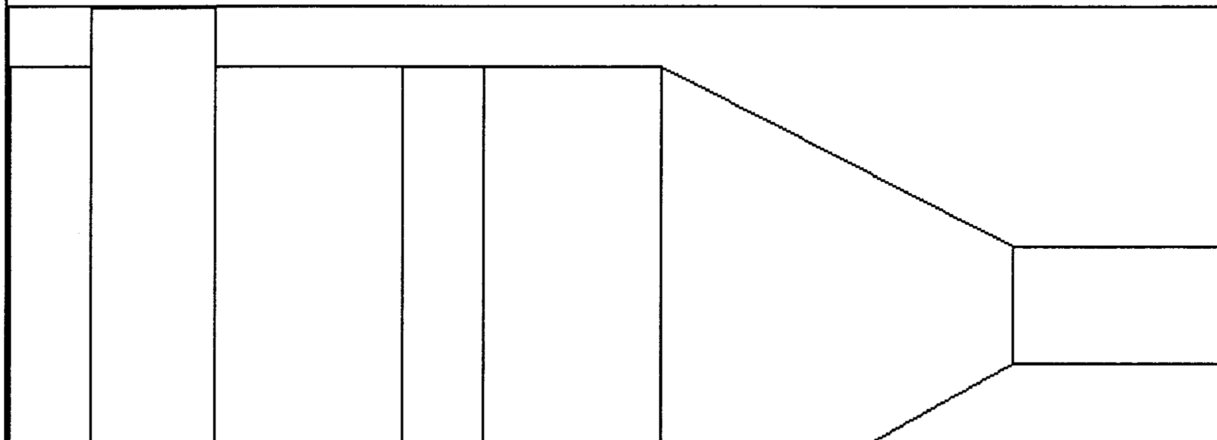

CHECK RT FWD MUX HUD DIGITAL DATA CKT
NOTE
3 of 3
An open reading (6 ohms or more), a short (0 ohms), or a short to case is unacceptable.
Press F1_OK to acknowledge Note.
F1_OK
F8_Help
Highlig
F1_OK
F8_Help

CHECK RT FWD MUX HUD DIGITAL DATA CKT

1. **Verify 2.0 ohms.**

○ **OK**

◉ **NOT OK**



Highlight appropriate choice, and press F1_Next to continue.

F1 Next | F5 Graphic A

CHECK RT FWD MUX HUD DIGITAL DATA CKT

FOLLOW-ON TASKS

- ☐ **Close door 1101.**
- ☐ **Perform HUD operational checkout.**
- ☐ **Perform HUD BIT.**
- ☐ **Connect connector 9472P1/1.**

Press F1_Postpone for all tasks, F2_Access for Follow-On Tasks, or F3_Completed to toggle checkmark.

F1_Postpone | F2_Access | F3_Comple | F7_Previous

Best Actions

RECOMMENDED ACTION: CHECK RT FWD MUX TRANSFORMER

ACTIONS	MINS	PROB	AVAIL
1. CHECK RT FWD MUX TRANSFORMER	5		N/A
[redacted]			Yes
3. REPAIR WIRING, RT FWD MUX AND HUD EU	80	.25	Yes

Press F1_Procedur to perform the highlighted procedure.

F1_Procedur | F3_Tests | F4_Repairs | F6_Order? | F7_Cancel

REPLACE RT FWD MUX MAT ASSY, 9476A2

INPUT CONDITIONS

PERSONNEL RECOMMENDED: 1

SUPPORT EQUIPMENT:

None

SUPPLIES (CONSUMABLES):

None

REFERENCE MATERIALS:

None

Press F1_Next for Required Conditions.

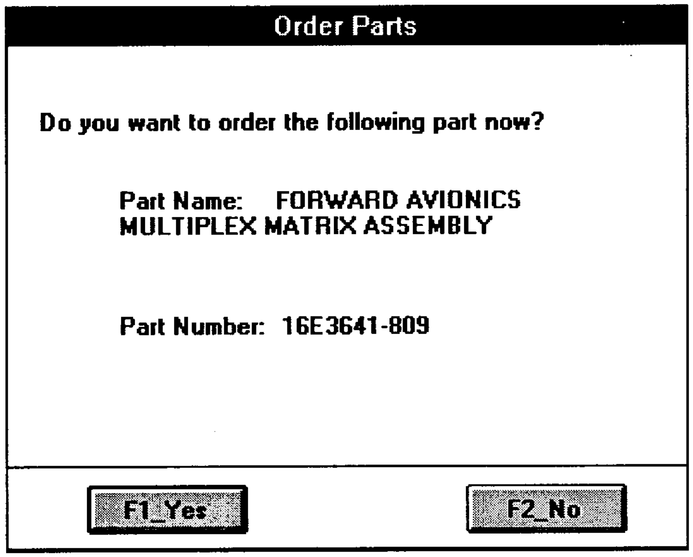
F1_Next | F4_Ref Matl | F7_Previous

REPLACE RT FWD MUX MAT ASSY, 9476A2

REQUIRED CONDITIONS

☒ Aircraft safe for maintenance.

Press F1_Next to begin the procedure, or F3_Completed to toggle checkmark.


Order Parts
Do you want to order the following part now?
Part Name: FORWARD AVIONICS
MULTIPLEX MATRIX ASSEMBLY
Part Number: 16E3641-809
F1_Yes
F2_No

REPLACE RT FWD MUX MAT ASSY, 9476A2

SUB-TASK:

☐ 1. Remove right fwd mux matrix assembly, 9476A2

Press F2_Access for Sub-Task, or F3_Completed to toggle checkmark and indicate sub-task completion.

F2_Access | F3_Comple | F7_Previous

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